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DEVONIAN ROCKS OF CENTRAL TEXAS

BY V. E. BARNES, P. E. CLOUD, JR., AND L. E. WARREN

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ABSTRACT

Information now available on the stratigraphy and areal distribution of Devonian rocks in the Llano uplift of central Texas is here summarized. Lower, Middle, and probably Upper Devonian rocks occur in this region. In upward succession the named units are the Pillar Bluff limestone and the Stribling, Bear Spring, and Zesch formations. The last two names are new with the present paper. The rocks are principally calcareous; but the Stribling and Bear Spring formations contain chert, and the Zesch formation is highly siliceous. Some unnamed calcareous, calcareo-

phosphatic, and siliceous rocks of Devonian and probable Devonian age are also described. All the units recognized appear to be thin and patchy in distribution. Except for outcrops of the Stribling formation, known occurrences are mostly fillings in solution structures of various sorts. Devonian rocks are now known from all quarters of the Llano uplift, where their presence was generally unknown previous to June 1945.

INTRODUCTORY REMARKS

The presence of Devonian rocks in the Llano uplift of central Texas was announced by the writers in 1945. Since this announcement was made additional information has been obtained, demonstrating the presence of rocks of Devonian age in all quarters of the Llano uplift (Fig. 1) and showing that some of the units occur more widely than had previously been known. Four Devonian formations are now known, representing Lower, Middle, and probably Upper Devonian. The present paper presents the new data and summarizes that previously announced.

The probable correlation of the Devonian rocks now known from central Texas is shown in Figure 2. Although the new faunal elements are yet to be described, the fossils from the various units were studied in sufficient detail to establish correlations within the limits indicated by this chart. Faunas similar to those listed in the present paper are illustrated in publications cited in the bibliography, and some of the species are figured in the excellent reference *Index fossils of North America* (Shimer and Shrock, 1944).

Other occurrences of Devonian rocks will probably be found at the surface in central Texas. The finds here described were purely incidental to stratigraphic work on the Ellenburger group (Lower Ordovician), and pockets or wedges of Devonian rocks might occur anywhere that Ellenburger and Carboniferous beds are stratigraphically juxtaposed. Even rocks of later Ordovician and Silurian age are to be looked for along this uncomformable zone, the possible former presence of Middle Ordovician rocks has already been indicated by the occurrence of reworked conodonts in lower Mississippian strata (Barnes, Cloud, and Warren, 1945, p. 176; not "in the Ellenburger group" as erroneously recorded by Ellison, 1946, p. 99).

The text of this report was prepared by Barnes and Cloud. Warren shared in the original discovery, assisted with the later field work, and drafted most of the illustrations.

ACKNOWLEDGMENTS

This paper was prepared under a co-operative arrangement between the Bureau of Economic Geology, of the University of Texas, and the Geological Survey, U. S. Department of the Interior.

Grateful acknowledgment is made to Dr. G. A. Cooper of the U. S. National Museum, who reviewed the faunal identifications, amended some, and verified most of the stratigraphic determinations that were made on the basis of macrofossils. Thanks are also expressed to Dr. W. H. Hass, who studied and reported on some of the conodonts obtained from samples submitted by the authors.

FIGURE 1.—*Index map showing location of known Devonian rocks and Ordovician–Carboniferous contact in central Texas*
Adapted from the U. S. Geological Survey, Geologic map of Texas (Darton, Stephenson, and Gardner, 1937).

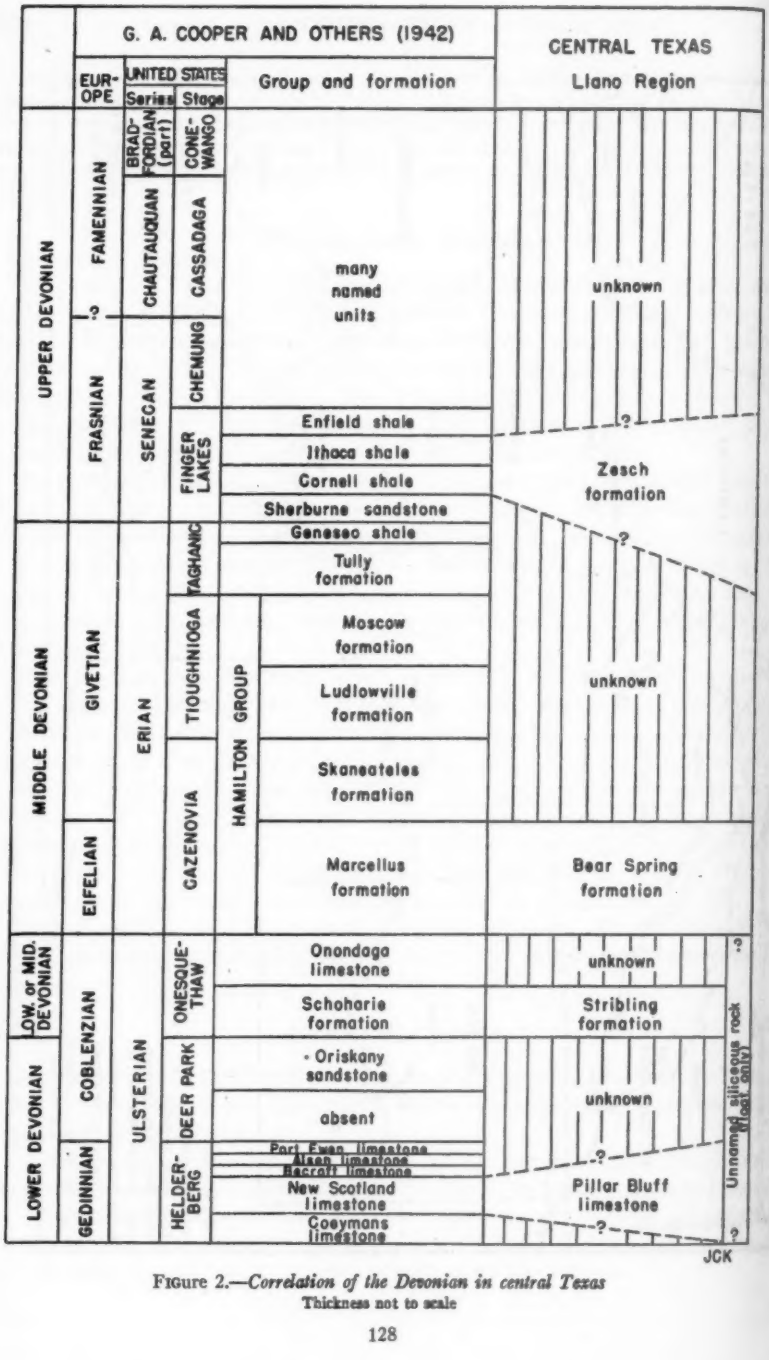

FIGURE 2.—*Correlation of the Devonian in central Texas*
Thickness not to scale

STRATIGRAPHY

LOWER DEVONIAN

Pillar Bluff limestone.—The name Pillar Bluff was proposed (Barnes, Cloud, and Warren, 1945, p. 166) for calcitic rocks carrying a fauna of Helderberg age. The type locality is an ancient joint or cave filling at Pillar Bluff on Pillar Bluff Creek, 5 miles southwest of Lampasas and just south of the Lampasas County line in northern Burnet County. This pocket of Lower Devonian rocks, replete with fossils, is surrounded by limestone and dolomite in the *Ceratopea "keithi"* zone of the Honeycut formation of the Ellenburger group (Lower Ordovician). It lies about 30 feet vertically below the lower margin of the covering debris that conceals the overlap of the Carboniferous strata on the Ellenburger rocks at this place.

The general geologic environment of the occurrence is shown on a geologic map by Plummer and Grant (1940), and Figure 3 of the present paper shows the local relationships. Fossil locality TF-273,[1] the type locality, may be reached by road from the Lampasas courthouse as follows: Go west and then south 1.3 miles on U. S. highway No. 281, turn west at the south edge of Panther Park, and follow the Naruna road 4.5 miles to a bend in the road. The locality is about 750 feet south-southeast of this bend and 340 feet east of the rock pillar at Pillar Bluff, on the west side of a northwest trending interior fence on the F. M. Bodenhamer ranch.

The known areal extent of the Pillar Bluff limestone is small. The discovery locality (TF-273) (Pl. 1, figs. 2, 4) consisted of a thin film of highly fossiliferous rock plastered against a ledge of limestone of the Ellenburger group, with 9 medium-sized blocks and 10 or 12 small blocks of similar material scattered over the adjoining 50 square feet. Six of the larger blocks and all the small ones were later pried loose and cracked up in search of fossils, so only about a third of the original occurrence remains. Search near by revealed only minor patches of rock with the prolific macrofauna of the discovery blocks.

No section or estimate as to thickness can be given for the Pillar Bluff limestone because of the peculiar manner in which it is preserved. The lack of brecciation and the coquinalike nature of the rock at locality TF-273 (Pl. 1, fig. 2) indicate that the sediments from which it formed either accumulated in openings in the clean-swept Ellenburger floor of the Helderberg sea as a result of wave action or were trapped by the collapse of underlying cavern roofs previous to lithification. The crowded and disjointed fossil shells in the Pillar Bluff limestone certainly are not preserved in the attitudes of life, yet the Pillar Bluff limestone is remarkably unmixed with and uncontaminated by its Ellenburger host rock. The latter condition rules out the likelihood of the entrapment of these shells by collapse and suggests the accumulation of dead shells in an opening at the sea floor.

The lithic character of the Pillar Bluff limestone is predominantly of two types. One is a fine- to coarse-grained, yellowish-gray to ivory-colored, fairly pure limestone, crowded with fossils and breaking easily when struck with a hammer. The residue from dissolution of this rock in acetic acid is roughly 5 per cent of total original volume

[1] Collections made by Cloud are numbered serially, with "TF" standing for Texas fossils. These collections are available for study at the U. S. National Museum.

and consists of dolomite rhombs, crystalline quartz, scattered crystalline opaque minerals, fragments of inarticulate brachiopods, and a few conodonts. The second type of limestone is fine- to very fine-grained; gray, dull yellow, or olive drab, ranging to gold and light bronze with roan splotches; is slightly dolomitic; has few or no

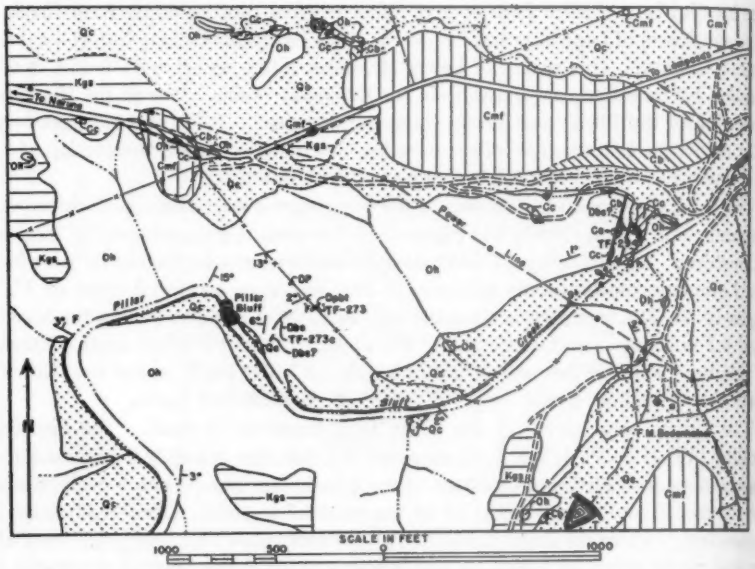

FIGURE 3.—*Geologic map of vicinity of Pillar Bluff, northern Burnet County, Texas*

Base from U. S. Department of Agriculture, Soil Conservation Service, aerial photograph CJC-47-133, 1940. Geology by P. E. Cloud, Jr. 1944–1945.

Explanation:

Qc	Quaternary cover: alluvium, colluvium, and undifferentiable slope wash.
Kgs	Cretaceous (?), gravel and sand: probably representing basal Cretaceous overlap.
Cmf	Pennsylvanian Marble Falls limestone (unrestricted): dark gray to black.
Cb	Mississippian, Barnett formation: dark petroliferous shale and minor limestone.
Cc	Mississippian, Chappel limestone: crinoidal, dirty brownish gray.
D(?)	Devonian (?): conglomeratic and phosphatic rock containing fragments of "fish".
Dbs	Devonian, Bear Spring formation: yellowish, grayish, and greenish limestone containing phosphatic pellets, macrofossils, and conodonts (TF-273 c).
Dbs(?)	Devonian, Bear Spring (?) formation: western occurrence similar to above, but no fossils seen; eastern occurrences yellowish to brownish, impure limestone with phosphatic pellets and numerous conodonts.
Dpbt	Devonian, Pillar Bluff limestone: fossil coquina at type locality (TF-273).

The four unlabeled small black spots, near TF-273, indicate very minor occurrences of the Pillar Bluff limestone.

Oh	Ordovician, Honeycut formation: limestone and dolomite in upper part of Ellenburger group (F indicates dating fossils).

All symbols are in standard usage or are explained in the text.

macrofossils; and is commonly very resistant to fracture. It has an earthy odor when damp and contains phosphatic granules and grains of glauconite and quartz. The residue from dissolution in acetic acid forms roughly 15 to 25 per cent of total original volume. In it dolomite rhombs predominate, phosphatic granules are common, quartz and glauconite grains are fairly common, and an occasional conodont is seen. While prying the fossiliferous blocks loose it was noticed that the finer-

grained, impure, sparingly fossiliferous limestone occurred below the more coarsely granular coquinalike rock.

The poorly preserved macrofauna of the Pillar Bluff limestone is considered to be of Helderberg age and is provisionally correlated with that of the New Scotland limestone and equivalent formations. (*See* Cooper and others, 1942.) Illustrations of faunas thought to be generally correlative are given by Tansey (1922), Hall (1861), Swartz, Schuchert, and others (1913), and Dunbar (1919).

Twenty-eight to 33 species in 24 genera and 4 phyla were found at locality TF-273: The following identifications and comparisons were reviewed and in part amended by G. A. Cooper (starred forms are considered to be most significant in correlation):

Cryptostomatous bryozoan, genus unidentified
Orbiculoidea sp.
Orthostrophia n. sp.
Parastrophinella, 1 to 3 new species
**Anastrophia verneuili* (Hall)
"*Stenoscisma*" *formosa* (Hall)
Camarotoechia, fragmentary specimens belonging to several species
**Uncinulus subpyramidatus* Tansey
Uncinulus nucleolatus (Hall)
Uncinulus cf. *U. mutabilis* (Hall)
Atrypa cf. *A. reticularis* (Linnaeus)
Coelospira cf. *C. concava* (Hall)
**Atrypina* cf. *A. imbricata* (Hall)
**Acrospirifer cyclopterus* (Hall)
Delthyris aff. *D. octocostata* (Hall)
**Meristella atoka* Girty
Meristella cf. *M. laevis* (Vanuxem)
Strophonella cf. *S. punctulifera* (Conrad)
Protoleptostrophia ? sp.
Leptaena cf. *L. rhomboidalis* (Wilckens)
Leptaenisca sp.
**Schuchertella* sp.
Levenea ? sp.
Rhipidomella sp.
Actinoptera cf. *A. communis* (Hall)
Platyceras sp.
Orthonychia cf. *O. plicatum* (Conrad)
"*Dalmanites*" sp.

A few conodonts were seen in acetic acid insolubles from locality TF-273.

Pillar Bluff (?) limestone.—Several feet below the type section of the Stribling formation, in Blanco County (Figs. 4, 5), is a pocket of impure limestone, enclosed by Ellenburger strata, from which the following macrofossils were collected (locality 16T-2-43P)[2]:

Orbiculoidea sp.
Delthyris ? sp. (dorsal valves only)
Camarotoechia ? sp. (ventral valves only)
Coelospira or *Leptocoelia* immature sp.
Meristella or *Athyris* sp. 1 (ventral valves only)
Meristella or *Athyris* sp. 2 (ventral valves only)

In addition, a few conodonts were seen in acetic acid residues from this limestone.

The evidence of these fossils alone is equivocal, and the rock could be of Helderberg, Oriskany, Onondaga, or even Silurian age. But the Stribling formation is early Onondaga (Onesquethaw stage of Cooper and others, 1942), and there is no evidence that the material in question reached its present position through an opening that penetrated the Stribling formation, thus representing strata that formerly overlay the Stribling rocks but are now absent from this vicinity. Moreover, there is little resemblance between the fauna of the pocket and that of the Stribling

[2] The Bureau of Economic Geology uses a system of locality numbers in which each of the 254 counties of the State is assigned a number. Blanco County is number 16. The "T" stands for Texas, and the remainder of the number designates the position within a county as recorded on aerial photographs for central Texas. On the maps the "16T" has been dropped to avoid crowding.

formation itself, so it is unlikely that the pocket filling represents Stribling rocks. Therefore, one must infer that the filling sediments were deposited in the pocket before Stribling time. The only pre-Stribling Devonian so far known in central Texas is the Pillar Bluff limestone, and the fossils from the pocket at locality 16T-2-43P are compatible with assignment to the fauna represented by those contained in the Pillar Bluff limestone at the type locality.

MIDDLE OR LOWER DEVONIAN

Stribling formation.—The Stribling formation was described and named by the writers in 1945, and a detailed description of its type section accompanied the original description. The type locality (Figs. 4, 5; Pl. 1, figs. 1, 3) is in Blanco County, 5 miles east of Johnson City at the foot of a bluff on the south bank and in a reach of Pedernales River known as Honeycut Bend. In addition to the outcrops in the vicinity of the type section (Figs. 4, 5) another is located in Honeycut Hollow about half a mile to the southwest, and others (Fig. 6) are located 4 and 5 miles northeast of the type section on the Cage ranch.

The Stribling formation, a graphic section of which is given in Figure 5, is 11 feet thick and consists of a basal sandy limestone 1–2 inches thick, firmly joined with the Ellenburger beneath, and an upper limestone. The latter is mostly cherty, irregularly bedded, smooth fracturing, fossiliferous, and medium gray to beige-colored. Fossils collected from the type section are as follows:

"*Lingula*" sp.
**Leptocoelia* n. sp. aff. *L. flabellites* (Conrad)
Schuchertella cf. *S. woolworthana* (Hall)
**Eodevonaria arcuata* (Hall)
Anoplia nucleata (Hall)
Platyostoma sp.
"*Dalmanites*" sp.
"*Phacops*" sp.

Present knowledge of Devonian faunas will permit this assemblage to be assigned only to an Oriskany or Onondaga age. On the basis of the elements starred in the list above, and their occurrence with *Centronella* at locality 16T-2-27A_2, it is regarded as equivalent to the Camden chert of west Tennessee and its correlatives (Cooper and others, 1942). It is therefore assigned to the lower Onondaga (Schoharie).

In Figure 1 of Plate 1 the observer views the Stribling formation southwest along the face of the bluff at its type locality. Detail of the bedding of approximately the middle 4 feet of the type section is shown in Figure 3 of Plate 1. The intercalation of lenticularly polygonal limestone blocks with fissile beds, as shown in this figure, characterizes the Stribling formation and distinguishes it from any other formation known in the Llano uplift.

Cloud and Barnes (in press) describe the rocks above the Stribling, and, therefore, they are but briefly noted in the present paper. The Ives breccia (Plummer, *in* Bullard and Plummer, 1939, p. 15) rests upon the Stribling formation and is considered to be of basal Mississippian age. Above the Ives is a 7- to 8-foot interval which, on the basis of stratigraphic position alone, was at first incorrectly identified as the Chappel limestone by the writers (Barnes, Cloud, and Warren, 1945, p. 171). Fossils collected from this interval during the summer of 1945 and during February 1946 by G. A. Cooper and the writers are regarded by Cooper (oral communication)

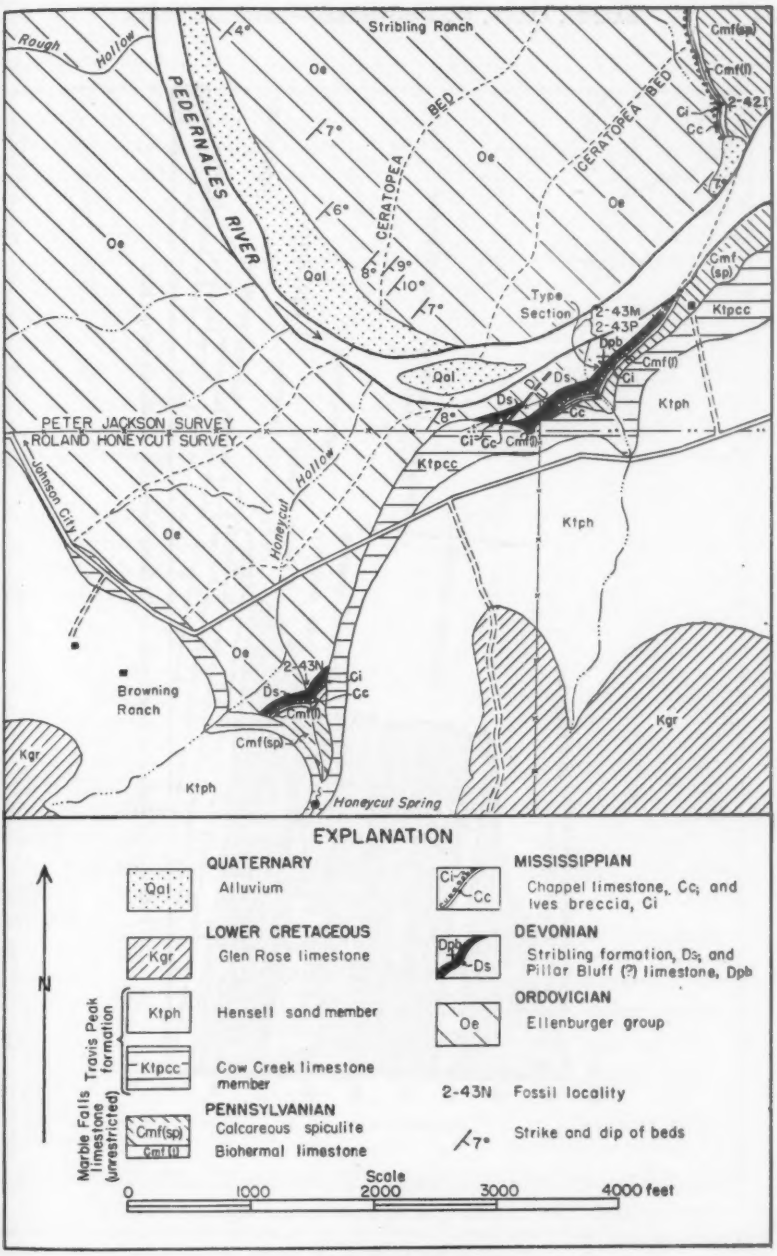

FIGURE 4.—*Geologic map of Honeycut Bend, Blanco County, Texas*

Showing location of Stribling formation. Base from U. S. Department of Agriculture, Soil Conservation Service, aerial photographs flown in 1940. Geology by V. E. Barnes and L. E. Warren.

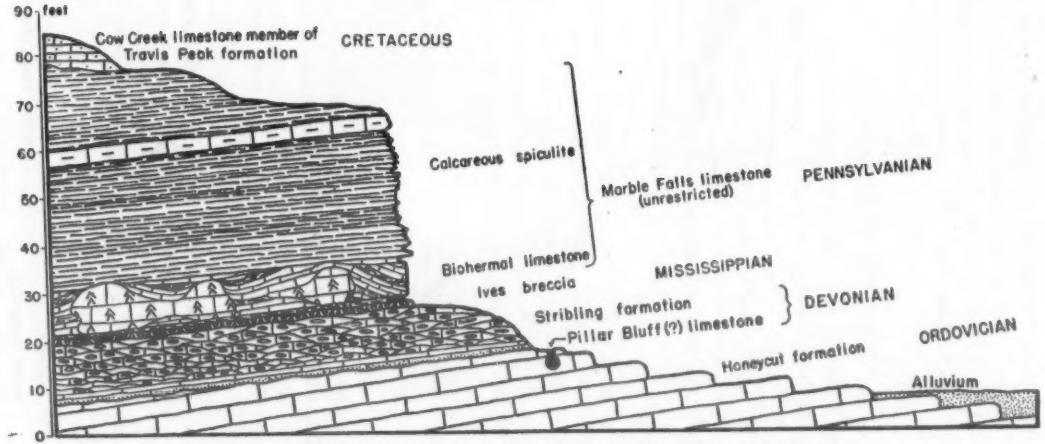

FIGURE 5.—*Diagram of type section of Stribling formation, Blanco County, Texas*

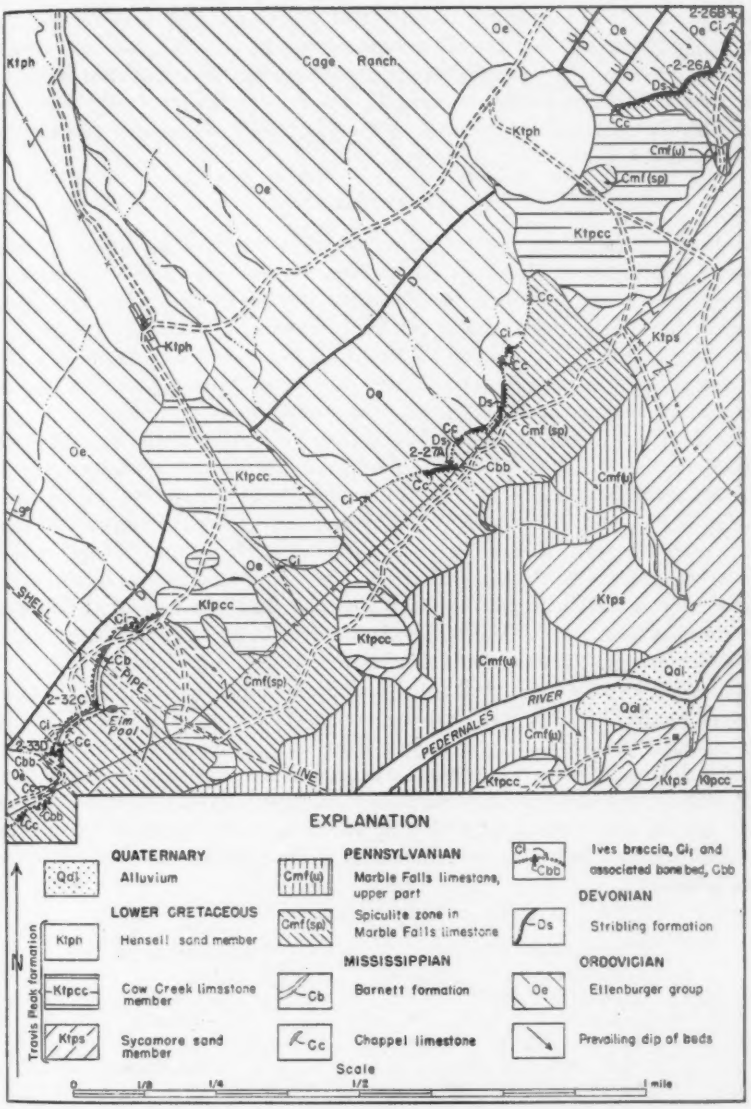

FIGURE 6.—*Geologic map of Elm Pool area, Blanco County, Texas*

Showing additional outcrops of Stribling formation. Base from U. S. Department of Agriculture, Soil Conservation Service, aerial photographs flown in 1940. Geology by V. E. Barnes and L. E. Warren[1]

as of Morrow age, and it is probably equivalent to the Sloan member of the Marble Falls limestone as defined by Plummer (1945). Chappel limestone, however, does outcrop within a short distance of the type section (Fig. 4), and it also outcrops sporadically along the Ordovician-Carboniferous boundary northeastward beyond the map area (Cloud and Barnes, in press, Pl. 3). Other units mapped (Figs. 4, 6) include the Barnett shale, three units of the Marble Falls limestone (unrestricted), and four units of the Lower Cretaceous.

MIDDLE DEVONIAN

Bear Spring formation.—About 2.2 miles airline east of Bear Spring, in Mason County, fossiliferous and in part cherty limestones of lower Middle Devonian age occur in an ancient collapse structure on the Roy Zesch ranch. In spite of their distance from Bear Spring these rocks are here named the Bear Spring formation, for this geographic feature is well known to the local people and has been taken as the name of an area mapped in connection with a detailed study of the Ellenburger group and including the locality noted (Cloud and Barnes, in press).

From the courthouse at Mason, Texas, the type locality of the Bear Spring formation may be reached as follows: Go southwest 8 miles by speedometer to the point where the road from Mason to White's Crossing crosses Honey Creek; from here the locality is 2000 feet airline N.75°W. It is near the head of the east fork of a draw that enters the south side of the valley of Honey Creek about 280 feet upstream from a rock cabin. At this point a patch of Devonian rocks, 240 feet long in a northeast-southwest direction and 140 to 160 feet wide, has collapsed into limestones of the Gorman formation (Lower Ordovician) and is in part overlapped by rocks of Mississippian age. The details of this feature are shown in Figure 7.

Rocks considered to be typical of the Bear Spring formation outcrop at the southwestern margin of this collapsed area and occur as float over most of it. These rocks are granular; yellowish or greenish brown to buff, bronze, olive brown, ivory, or nutria; and fossiliferous. Over the lower part of the collapsed area considerable dull-white to speckled-gray, porcelaneous to semiporcelaneous chert occurs in the float, but the fossils associated with it appear to be similar to those from the small patch of outcrop at the southwestern margin of the collapse. The following genera were noted:

Favosites
Cyathophyllum
Cystiphyllum
Aulopora sp.
Leptaena
Pholidostrophia
Pentamerella
Uncinulus
Delthyris
Fimbrispirifer
Atrypa
Athyris
Cryptonella
Platyceras
Conocardium

These indicate a lower Middle Devonian age and probable correlation with the Delaware limestone of Ohio, Michigan, and Ontario, and thus the Marcellus shale of the New York section. (*See* Cooper *et al.*, 1942.)

Because of the nature of its occurrence the true thickness of the Bear Spring for-

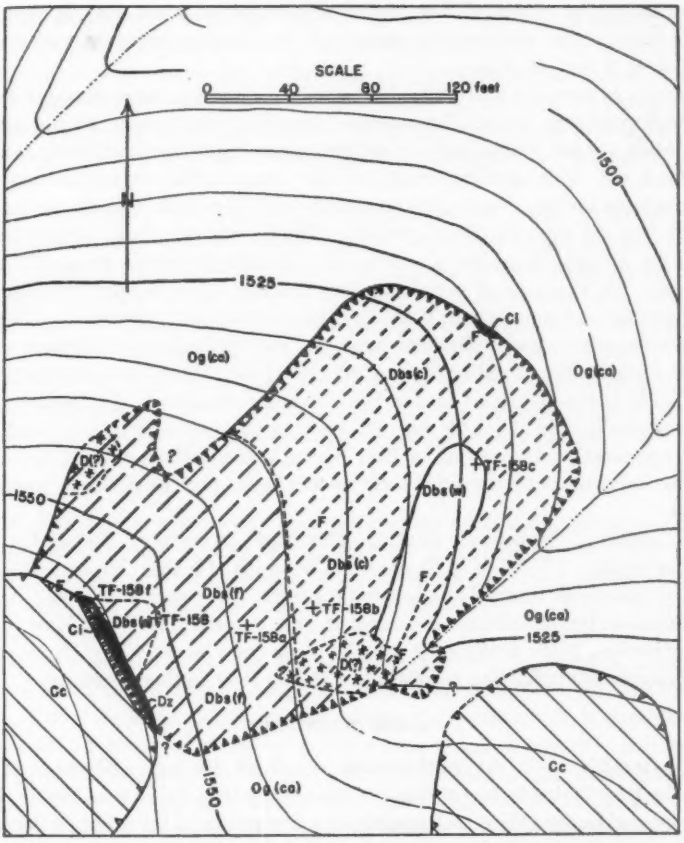

FIGURE 7.—*Geologic map of type locality of Bear Spring and Zesch formations, Mason County, Texas*

Alidade and plane table survey by V. E. Barnes and L. E. Warren, 1945. Geology by P. E. Cloud, Jr., 1944–1945.

Explanation:

- Cc — Mississippian, Chappel limestone: crinoidal; reddish, brownish, or olive gray.
- Ci — Mississippian, Ives breccia: siliceous, yellowish and brownish; phenoclasts crowded.
- Dz — Devonian, Zesch formation (solid black): highly siliceous limestone and leached silica rock; yellowish to brownish; contains scattered angular fragments of chert and a few macrofossils.
- Dbs(o) — Devonian, Bear Spring formation: *outcrop* of granular, brownish to grayish yellow, fossiliferous limestone.
- Dbs(f) — Devonian, Bear Spring formation: *float* of limestone similar to above.
- Dbs(c) — Devonian, Bear Spring formation: *chert*-bearing limestone float, and float of limestone associated with chert; the chert contains a few fossils, and the limestone many.
- Dbs(w) — Devonian, Bear Spring formation: *white* to cream-colored, fine- to coarse-grained limestone that is fossiliferous at TF-158c and sparingly so elsewhere.
- D(?) — Devonian (?): olive green to brown, laminated, ferruginous and phosphatic silica rock occurring only as float spread over and associated with float of the Bear Spring formation at the margins of the collapse structure.
- Og(ca) — Ordovician, Ellenburger group, calcitic facies of the Gorman formation.

Triangles at the contact lines indicate collapse of younger into older beds. The closely spaced triangles at the margins of the patch of Devonian rocks indicate pre-Mississippian collapse, and the widely spaced triangles indicate post-Chappel collapse. Either may have been rejuvenated at favorable times.

Other symbols are in standard usage or are explained in the text.

mation cannot be estimated, but several tens of feet of strata may be represented. The outcrop at the southeastern margin of the collapse probably represents only about 3 or 4 feet of strata.

Outcrops of granular white limestone standing almost on edge near the east side of the collapsed area contain *Pentamerella*, *Leptaena*, *Schuchertella*, *Atrypa*, and a few other fossils and are provisionally considered to belong to the Bear Spring formation.

Beyond the type locality, rocks of the Bear Spring formation are known from northern Burnet County, in the vicinity of Pillar Bluff (Fig. 3). A little west and south of the type locality of the Pillar Bluff limestone, dark, impure limestone containing phosphatic pellets was originally thought to belong to the Pillar Bluff limestone. On the basis of conodonts from this locality (TF-273c), however, W. H. Hass (personal communication, 1945) questioned the earlier correlation. Additional macrofossils subsequently obtained from the locality included a *Pentamerella* like the one from the type locality of the Bear Spring formation, and the linear outcrop at TF-273c is now assigned to the Bear Spring formation. The bedding at this locality actually dips about 60° into the linear zone of outcrop and, in combination with fragmentation and mixing of Bear Spring and Ellenburger lithic types at the margins, indicates post-depositional movement to its present position, probably by collapse.

Bear Spring (?) formation.—East of Pillar Bluff, in northern Burnet County, at and near locality TF-294 (Fig. 3) are small outcrops of a thin, impure, yellowish to brownish limestone containing phosphatic pellets. No macrofossils were found in this limestone; but conodonts are abundant, and, according to W. H. Hass (personal communication, 1945; 1946), they are like those from locality TF-273c, which contains macrofossils indicating correlation with the Bear Spring formation.

UPPER (?) DEVONIAN

Zesch formation.—At the southwestern margin of the same collapse structure in which the Bear Spring formation has its type locality (Fig. 7) is a thin, highly siliceous limestone and leached silica rock containing a few species of brachiopods that suggest faunal relationship to the Ithaca and Cornell shales of early Late Devonian age. It differs faunally and lithically from any other named Devonian unit in the Llano region and is here called the Zesch formation, for the ranch of Roy Zesch on which the type locality is situated.

The siliceous limestone of the Zesch formation attains a thickness of about 18 to 24 inches and thins to a feather edge. It is a brownish to yellowish and contains angular fragments of chert. It appears to grade upward into a chert breccia here assigned to the Ives breccia, but the few macrofossils obtained from it (TF-158f and float northeast from it) are clearly Devonian and include forms that ordinarily do not occur higher than fairly low Upper Devonian. They include *Echinocoelia*, *Tylothyris*, and a martinioid brachiopod similar to "*Reticularia*" *laevis* (Hall). These fossils have affinities as old as the late Middle Devonian Tully formation and as young as the early Late Devonian Enfield shale of the standard section in New York. According to Dr. G. A. Cooper (oral communication), however, they are most suggestive of the Ithaca and Cornell shales.

The Zesch formation rests on older Devonian strata (Bear Spring formation) and is collapsed into middle Ellenburger strata (Gorman formation); but it contains, as pebbles, occasional specimens of later Ellenburger Ceratopeas of an unnamed species called *Ceratopea* 5 by Cloud and Barnes (in press). If the rock that overlies the Zesch formation really is the Ives breccia, the apparent gradation between the two is probably due to mixing at the time the Ives was deposited, rather than to actual transition.

Zesch (?) formation.—Rocks possibly assignable to the Zesch formation occur about 5 miles southeast of Brady, in McCulloch County, near the northwest margin of a large collapsed syncline of Mississippian rocks north of Bald Ridge on the ranch of Mrs. May Brook Kothman. They are fine-grained, slightly arenaceous, yellowish- to greenish-gray, limestone which contains abundant *Orbiculoidea* and *Leiorhynchus*, small ambocoeliinid brachiopods, an occasional *Atrypa*, and the conodont *Icriodus*. *Atrypa* suggests a pre-Mississippian age and *Icriodus* indicates Devonian, while the ambocoeliinid, although not generically determined, suggests possible relationship to the Zesch formation, which contains the ambocoeliinid *Echinocoelia*.

DEVONIAN (?)

Impure, dark, calcareo-phosphatic rocks that fill cracks in the upper surface of the Ellenburger rocks in the vicinity of Cypress Mill and Honeycut Bend in Blanco County suggest, by their relationships, a Devonian or older post-Ellenburger age, and Devonian types of conodonts (*Icriodus*) have been found in acetic acid residues from some.

Other rock of possible Devonian age occurs as float at the margins of the collapsed pocket in which the Bear Spring and Zesch formations have their type locality (Fig. 7). This is a peculiar, olive-green to brown, finely laminated, ferruginous and phosphatic silica rock in which the laminations are commonly contorted and folded, apparently from sliding of the original unlithified sediments. Six thin sections of this rock were prepared in the thin-section laboratory of the U. S. Geological Survey, both parallel and normal to the bedding, and were studied for evidence of radiolarians or other microfossils. No fossils, however, were found. This rock occurs as float only, its stratigraphic position is not known, and it is not deemed worthy of a name. However, its marginal relationship to the known Devonian rocks of the collapsed area shown in Figure 7 suggests that it represents remanants of rocks that were dragged loose during collapse, and possibly came from below the Bear Spring formation. Its lithic character is distinctive, and it should be looked for in other parts of the Llano region and in the subsurface.

ECONOMIC AND HISTORIC IMPLICATIONS

The presence of Devonian rocks of widely varying age in central Texas suggests that equivalent sediments may have been deposited, perhaps to much greater thicknesses, in the adjacent subsurface. Possibilities for stratigraphic types of petroleum traps related to Devonian rocks of the ages noted should be good. The observed normal relationships of the described Devonian rocks to formations above and below are unconformable; and facies changes, elsewhere common to Devonian beds, are to

be looked for in the subsurface. Correlative rocks are well-known as producers of oil.

Middle Ordovician types of conodonts (*Cheirognathus*) have been found mixed with Mississippian and Devonian forms in rocks of basal Mississippian age at locality 16T-2-27A_1 (Fig. 6). Their occurrence suggests that strata of the Simpson group, another known producer of oil, may extend as far south as the Llano region in the subsurface.

The occurrence of the Devonian formations described proves that the major truncation of the Ellenburger rocks in the Llano region, and therefore in the adjacent subsurface, was essentially a pre-Devonian event. It could have occurred at any time between the deposition of Lower Ordovician and Lower Devonian sediments, but probabilities appear to limit it to post-Middle Ordovician and pre-Lower Devonian. Subsequent truncations and overlaps were many and complex; but none appears to have so profoundly affected the Ordovician rocks of the Llano region again during the Paleozoic era.

REFERENCES CITED

Barnes, V. E., Cloud, P. E., Jr., and Warren, L. E. (1945) *The Devonian of central Texas*, Univ. Texas, Pub. 4301, p. 163–177, figs. 42–46, pls. 9–10, 1943.

Bullard, F. M., and Plummer, F. B. (1939) *Paleozoic section of the Llano uplift*, Special mimeographed publication sponsored by West Texas and Fort Worth Geol. Soc., Texas Acad. Sci., and Univ. Texas, 20 pp., 6 illus.

Cloud, P. E., Jr., and Barnes, V. E. (In press) *The Ellenburger group of central Texas*, Univ. Texas, Pub. 4621.

Cooper, G. A., and Others (1942) *Correlation of the Devonian sedimentary formations of North America*, Geol. Soc. Am., Bull., vol. 53, p. 1729–1794.

Darton, N. H., Stephenson, L. W., and Gardner, Julia (1937) *Geologic map of Texas*, U. S. Geol. Survey.

Dunbar, C. O. (1919) *Stratigraphy and correlation of the Devonian of western Tennessee*, Tenn. Geol. Survey, Bull. 21.

Ellison, S. P., Jr. (1946) *Conodonts as Paleozoic guide fossils*, Am. Assoc. Petrol. Geol. Bull., vol. 30, p. 93–110, figs. 1–3.

Hall, James (1861) *Descriptions and figures of the organic remains of the lower Helderberg group and the Oriskany sandstone*, Geol. Survey N. Y., Paleont., vol. 3, pt. 2 (plates).

Plummer, F. B. (1945) *Stratigraphy of the Lower Pennsylvanian coral-bearing strata of Texas*, Univ. Texas, Pub. 4401, pp. 63–76, fig. 1, pls. 11–13, 3 charts, 1944

Plummer, F. B., and Grant, B. F. (1940) *Geologic map of area southwest of Lampasas, Texas*, Univ. Texas, Bur. Econ. Geol.

Shimer, H. W. and Shrock, R. R. (1944) *Index fossils of North America*, John Wiley & Sons, Inc., New York.

Swartz, C. K., Schuchert, Charles, and Others (1913) *Lower Devonian*, Md. Geol. Survey, text and pls. 17–98 in Devonian plates.

Tansey, V. O. (1922) *The fauna and the correlation of the Bailey limestone in the Little Saline Creek area of Ste. Genevieve County, Missouri*, Mo. Bur. Geol. Mines, 2d ser., vol. 17, pp. 166–212, pls. 40–56.

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FIGURE 1. TYPE LOCALITY OF STRIBLING FORMATION (16T-2-43M)
Honeycut Bend of Pedernales River, Blanco County. Figure at X marks top, and packsack at Y marks base of Stribling formation, which is 11 feet thick at this place.

FIGURE 3. DETAIL OF BEDDING IN STRIBLING FORMATION AT TYPE LOCALITY
Approximately the middle 3.5 feet of formation is shown. Lenticular plates of limestone and chert and shingle-like arrangement are characteristic.

FIGURE 2. DETAIL OF PILLAR BLUFF LIMESTONE AT TYPE LOCALITY
Letters X and Y mark same blocks in Figure 2 as in Figure 4.

FIGURE 4. TYPE LOCALITY OF PILLAR BLUFF LIMESTONE (TF-273), BURNET COUNTY
Dashed line around X and Y outlines discovery pocket, and that around Z outlines film of Pillar Bluff limestone that is plastered against ledge of Honeycut formation. Photograph from top of fence.

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SOLUTION SCULPTURING IN LIMESTONE PEBBLES

BY HAROLD W. SCOTT

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ABSTRACT

A complex system of sculpturing in limestone pebbles is referred to as a pattern of solution morel. It consists of ridges, grooves, pinnacles, truncated pinnacles, pinnacle caldrons, micronatural bridges, and other features.

The pattern is developed in pebbles that consist of impure limestone which had original convex surfaces. The sculpturing progresses through the stages of youth, maturity, and old age. These stages are recognized by the appearance of new forms and the destruction of old. The pebbles are part of the gravel in a terrace of Circle age from a semi-arid region.

INTRODUCTION

Limestone pebbles and cobbles bearing a peculiar solution pattern on their upper surfaces and a caliche shell attached to their bases have been found in Wind River Basin, Wyoming, a semiarid region where the effects of solution are often as striking as those of the wind.

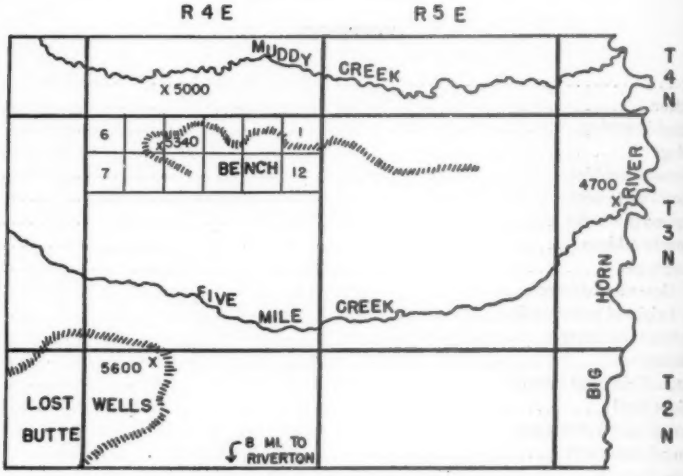

FIGURE 1.—*Map of a portion of Wind River Basin, Wyoming*

The corrosion pattern developed on the surface of these limestone pebbles exhibits many details which need both description of form and an analysis of processes involved in their development. Certain features have been observed to be common to all specimens in the same stage of destruction. The intricate pattern has been observed to progress from the simple to the complex and final destruction. This report describes the forms produced and interprets the processes involved.

It is suggested that solution-facetted pebbles could be produced only in dense limestone or on pebbles whose original surfaces sloped 3° to 6°, mostly in one direction. If the pebbles have convex surfaces and are not of the dense Solenhofen or Finlay type, but contain fossils and are somewhat crystalline, then sculpturing of what is here referred to as the solution-morel type will develop.

Acknowledgment is made of the constructive criticisms of Dr. J Harlen Bretz, University of Chicago, and Dr. Leland Horberg, Illinois Geological Survey.

PHYSIOGRAPHIC SETTING

Solution-morel pebbles were found in the summer of 1945 in Wind River Basin on a terrace veneered with gravel. The pebbles are abundant 5 miles north of Lost Wells Butte in the SE. 1/4 Sec. 5, T. 3 N., R 4 E., at an elevation of 5350 feet (Fig. 1). Morel pebbles can be found along the crest of the same ridge east toward Big Horn River.

The gravel is composed of water-worn pebbles derived for the most part from Paleozoic rocks outcropping in the Wind River and Absaroka mountains. Limestone pebbles from the Madison (Mississippian) formation and quartzite from the Flathead (Cambrian) predominate. They have been transported from 50 to 80 miles. The quartzite pebbles are smooth and elliptical. The limestone pebbles were also originally moderately smooth and ovate but have been complexly sculptured by corrosion.

The terrace on which the gravels rest is the divide between Muddy and Five Mile creeks. It is part of an extensive terrace that can be recognized in many parts of Wind River Basin. Where the solution-morel pebbles were collected, the terrace is about 350 feet above the stream.

Blackwelder (1915) describes the Crowheart Butte surface in the west end of Wind River Basin as part of the Black Rock erosional cycle and the next lower terrace as part of the Circle cycle. The terrace containing the solution-morel limestone pebbles is identified as part of the Circle cycle. This does not mean that the pebbles have been subjected to weathering since Circle time, because there is no way to determine the date at which the pebbles were uncovered.

TABLE 1.—*Time scale*

Epoch (After Blackwelder, 1915)	Erosional Cycles	Glacial Stages
Pleistocene		Pinedale
	Lenore	
		Bull Lake (Early Wisconsin)
	Circle	
		Buffalo
	Black Rock	
	Union Pass	

TERMINOLOGY

A brief discussion of terms is presented because most of those now in use are unsatisfactory in designating the corrosion pattern developed on Wind River Basin limestone pebbles.

RILLENSTEINE: Rillensteine, as commonly used in both Europe and America, designates narrow rills or channels a millimeter or less in width, very shallow, and possessing most commonly a U-shaped cross section. They may occur on facetted surfaces or on the walls of almost any corroded structure.

LAPIES: Large solution furrows with intervening ridges are known as lapies or karren. Lapies are developed on surfaces which are inclined more than 20°. Their width is usually measured in inches or feet. Cvijic (1924) has described extensive areas of lapies in the Dinaric karst areas of Europe.

TINAJITA: Udden (1925), King (1927), and Smith and Albritton (1941) have described many tinajitas. Smith and Albritton (personal communication) describe them as shallow solution depressions with smooth floors and an elliptical to circular outline, most of them having a "mean width generally exceeding 5 times the depth." They stress the dense homogeneous character of the limestone in which tinajitas occur and point out that such depressions are formed on slopes of less than 3°.

SOLUTION-FACETS: Udden (1941) and Bryan (1929) describe pebbles collected in semiarid regions from southern Texas, Montana, and New Mexico which were characterized by facetted surfaces. Most of the facets were rimmed with a narrow raised edge. Bryan explained the facets as due to progressive solution removing the convex surface of the pebble and ultimately developing a nearly plane surface bounded by a narrow rim.

SOLUTION FURROWS AND RIDGES: The terms furrows and ridges are too general in application to be restricted in meaning. They are here considered to pertain to any size of solution feature from rillensteine to lapies.

SOLUTION-MOREL PEBBLES

GENERAL STATEMENT

Solution-morel sculpturing is a pattern of anastomosing ridges and furrows broken by a few pinnacles rising above the level of the ridges. The pattern is further complicated by small pits in the top of pinnacles, by larger basins into which several furrows may lead, by minute rillensteine, and other solution features. The entire pattern resembles that of the morel mushroom. It is from this plant that the name "solution-morel" is taken (Morhela—old German, meaning sponge).

In general, solution-morel pebbles are ovate in outline. Their outer margins conform to the perimeter of the original pebble. The main changes in shape are (1) the sculpturing on the upper surface, (2) the general thinning, and (3) the addition of caliche on the under surface. The outer margin of most morel pebbles is characterized by a sharp rim which is often paralleled by a shallow inner groove. The marginal rim and groove may not be continuous; the latter in many cases is poorly developed. The walls of the pinnacles, as well as the floors of the basins, may be marked with rillensteine but more commonly are coated with a thin film of secondary lime.

FACETTED PINNACLES

The development of the facetted pinnacle is a unique feature of morel pebbles. Practically all pinnacles, as well as ridges, have truncated tops. This is true regardless of the height or diameter of the pinnacle or thickness of the ridge. The facetted tops are inclined planes that range from 2° to 45°. There is no uniformity in the direction of slope, and the facetted surfaces on adjacent pinnacles may slope in opposite directions. The center of the facetted surface has the gray color of the unaltered limestone. The outer margin is represented by a narrow ring of light-gray to buff material which is believed to represent redeposited calcium carbonate on the side walls of the pinnacles. This outer ring appears to be very slightly less soluble

than the original limestone. It tends to stand up as a very faint rim bounding the facet and in some specimens it forms a more pronounced rim.

The development of the facets on the pinnacles and ridges appears to be related to the film of secondary lime on the side walls. Probably the thin film on the side walls

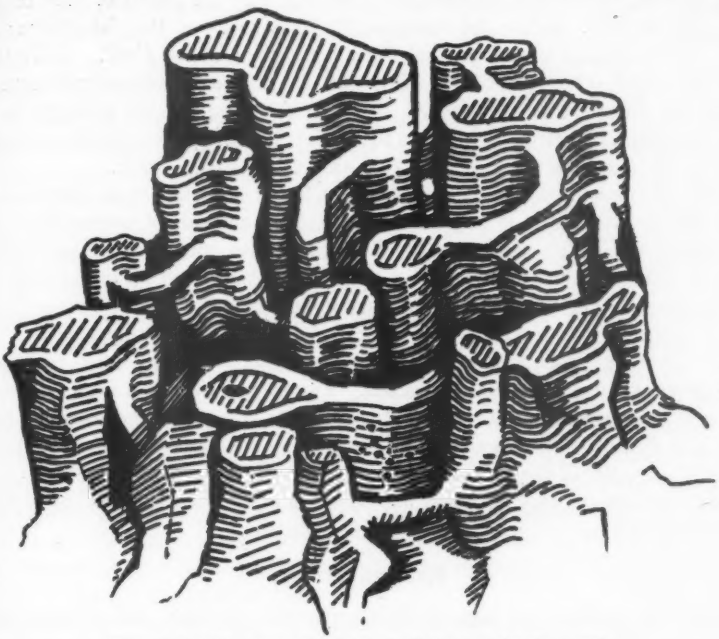

FIGURE 2.—*Diagrammatic sketch of solution morel pattern,* ×3

of pinnacles causes a slight retardation in the rate of solution around their margin and, therefore, the crest is maintained as a truncated surface. The film of lime on the side walls cannot be explained simply by ponding of water in the furrows or basins, because the tops of the pinnacles and ridges rise far above the outlet points. If the light-gray film is correctly interpreted, it probably originated by the evaporation of a film of water drawn up the side walls through surface tension.

Immediately after rainfall ceases, the surface of the pebble is moist. The small basins and furrows are ponded, but the protruding pinnacles and ridges are covered with only a thin film of water. The hot desert sun will tend to dry the pinnacle walls. As a result of rapid evaporation, water will be drawn from the basins and furrows up the sides of pinnacles and ridges. All walls, therefore, will be coated with a film of secondary lime. It will be continuously deposited on the walls as long as water remains in the basins. The only material deposited in the basins will be that derived from the evaporation of the last film of water after each rain. Each succeeding rainfall has more secondary lime to remove from the walls than it has from the basins; therefore, the basins continue to be deepened, whereas the protruding

features are maintained or even exaggerated. Solution is always greatest in the basins and at the base of the pinnacles. As a result the pinnacle walls remain vertical to overhanging.

The above explanation may be adequate for the development and maintenance of the pinnacles, but it does not completely explain why the pinnacles have inclined truncated surfaces. Smith and Albritton (1941) have shown that facetted surfaces on a larger scale are best developed when the surface slopes 3°–6°. Hoffmeister and Ladd (1945) demonstrated that a facet can be artificially produced in lithographic Solenhofen limestone on an inclined surface. They applied the principle to the origin of elevated limestone terraces in the Pacific, but it appears that the same principle cannot be applied to the facetted pinnacles of morel sculpturing.

There are a few pinnacles with rounded tops, but in no instances are these rounded tops symmetrical. Even if they were symmetrical we could not assume that every part would receive an equal amount of solution. Assuming that we start with a pinnacle that has an asymmetrical top and has side walls covered in part with secondary lime, the convex surface of the apex will gradually be reduced through solution to a point where the film of secondary origin makes its first appearance. The convex top will go down more rapidly than the side walls that are coated, until finally an approximately plane surface is reached. This surface will be inclined (1) because of the original asymmetry of the apex, and/or (2) because of the irregular upper margin of lime on the side walls. The direction of inclination will be toward the side where the rim of the secondary lime was at its lowest point.

The facet surfaces may be gently undulating, and some of them are characterized by shallow to deep pits, here called pinnacle caldrons.

PINNACLE CALDRON

When a facetted surface becomes slightly undulatory a thin film of water can remain in the lowest spot, whereas the margin of the pinnacle facet will remain dry. Solution, therefore, is occasionally accelerated on the crest of the pinnacle. The center of the facet is slowly depressed until a shallow and somewhat rounded pit appears. Such pits resemble miniature volcanic caldrons. Occasionally they are deeply corroded and extend to the bottom of the pinnacle. It is not entirely clear how the dissolved mineral matter is removed from such caldrons. The mechanical force of falling raindrops probably causes the ponded water, with its dissolved mineral matter, to splash out of the caldron. Wind would also be an agent in removing water from the shallow pinnacle caldrons. The caldrons do not occur in pinnacles with steeply inclined facets. Probably they were developed in pinnacles that originally had gently inclined facets, and the principle involved in their initial formation is probably the same as described by Smith and Albritton (1941) for the development of tinajitas in solution-facetted limestone blocks.

MOREL BASIN

General statement.—The term tinajita has been applied to relatively shallow depressions with relatively smooth floors and irregular walls. Their size is usually controlled by the size of the joint block in which they were developed. They are

usually measured in feet; Udden (1925) describes one covering more than 70 square feet. Smith and Albritton (1941) describe several which are smaller, commonly about 4 square feet in surface extent.

A tinajita is developed on flat surfaces with less than 3° of slope. Obviously the larger depressions in limestone pebbles cannot be designated as tinajitas. One limestone pebble from the Wind River Basin locality has a surface area of 20 square inches. In it are developed three basins distinctly larger than any of the pits or furrows. Each of these three larger basins is approximately 1 square inch in size. Their floors are concave, the walls irregular and mostly steep. The walls are not smooth and continuous but are represented by a series of fluted solution-pinnacles of various heights. The diameter of a basin is only slightly less than the greatest height of the basin wall. The diameter to height ratio is about 1:.75, whereas the same ratio in a tinajita is 5:1. The term morel basin is here proposed for solution basins in limestone pebbles which are smaller than tinajitas but larger than pits, and in which the diameter-height ratio is about 1:.75.

Origin of morel basins.—In the field observations of Smith and Albritton (1941) and the experimental studies of Hoffmeister and Ladd (1941), the inclination of the surface of the limestone block was determined to be the most important factor in the development of tinajitas and rimmed solution facets. However, they repeatedly pointed out that the limestone in which these solution structures were produced was of a fine-grained lithographic type. Smith and Albritton have demonstrated the significance of slope in the development of solution features in the Finlay formation, a dense, evenly bedded limestone. They concluded that shallow depressions called tinajitas are characteristic of limestone surfaces with an inclination of less than 3°; that facetted surfaces develop when the inclination is 3°–6°; and lapies are produced on steep slopes ranging from 20° to 90°.

In the limestone pebbles from Wind River Basin, we are not dealing with a similar set of conditions. The pebbles originally had convex, upper surfaces and were not composed of compact homogeneous limestone. The pebbles are from the Madison formation and contain fossil fragments of crystalline calcite. The limestone is dark gray and contains a considerable amount of impurities. Morel basins may have been started in shallow depressions due to areas of greater solubility, or they could represent an enlargement of initial depressions formed by mechanical wear during the early history of the pebble when it was transported by streams.

Our interest lies in the enlargement of the initial depression into a morel basin. Unlike the tinajita, water could not flow down a plane or gently sloping surface and over a facet rim. However, when water fell in the shallow basin it would rise until it flowed over a notch between pinnacles and entered a solution furrow. By flowing through a series of furrows and over successively lower notches it would reach the edge of the pebble and carry dissolved mineral matter away from the basin. Small showers instead of heavy downpours are common in semiarid Wind River Basin in the summer months. Therefore, even though the surface extent of pebbles is small, the basins would occasionally slowly fill with water, and mineral matter would be removed by the process outlined.

Hard rains would fill the small morel basins quickly, and the water would be re-

moved by the force of falling rain and by the wind. To observe the effect of a moderately strong wind and falling water, a simple test was made with a sprinkling system and an electric fan operating to represent a moderately strong wind. As long as the artificial rain continued to fall, the basins and furrows remained filled, and considerable splashing of water on the side walls took place. When the source of water was cut off, the wind removed most of the water from all depressions except for small quantities in the deeper furrows and the bottom of morel basins.

MICRO NATURAL BRIDGES

Some of the thin walls between pinnacles are pierced by round to ovate holes, thus developing miniature natural bridges. There is no known example of such a hole piercing the wall at the base of the pinnacle. The opening occurs at about half the height of the wall and in every observed case is circular to ovate. The portion of the wall above the hole is thin and fragile. Apparently, the openings represent points in the side walls which were slightly more soluble than the surrounding surface. At several places small round holes have been developed only part way through a wall.

The collapse or destruction through solution of the bridge develops a notch. A series of notches produce sharply serrated ridges.

RILLENSTEINE

Narrow grooves, a millimeter or less in width, formed by corrosion are generally classified as rillensteine. They can be found on many of the solution-morel pebbles. In the early stage of development, rillensteine occur as parallel grooves on the flanks of the pebble extending from the margin of the morel structure downward to the edge of the caliche. In later stages of morel development rillensteine can be found in the morel basins and occasionally around the marginal rim. They occur rarely on the vertical walls of pinnacles, because the walls are surfaces of deposition rather than solution. They appear as structures superimposed upon the morel pattern. It is unlikely that any of them are ever enlarged to form morel furrows.

MARGINAL RIM AND GROOVE

Most pebbles show a well-developed marginal rim with a very narrow, sharp edge. It may be continuous and is well developed only in pebbles which have reached the mature stage of development. Bryan (1929) reported a rim on solution-facetted pebbles and ascribed the origin of the rim as due in part to "protection by the secondary calcite or travertine." He pointed out, however, that similar rims have been reported as occurring on pebbles composed of substances other than limestone, and suggested that the development of a rim might have a more general explanation. Hoffmeister and Ladd's (1945) experiment in artificially producing a rim satisfactorily explains the development of such a feature on a gently tilted plane surface because a greater quantity of water will flow over the medial and lower portions of a tilted plane surface than over the upper portion or along the lateral margins. As a result, solution is not as rapid along the lateral and upper margins and a rim develops. However, the formation of a rim on a facetted or morel pebble cannot be ascribed entirely to the same process.

If the lower portion of a limestone pebble is buried in soil, it may receive a deposit of calcium carbonate, whereas the upper portion will undergo solution and in time will either be facetted or a morel structure will be produced. In either case, the upper convex outline of the pebble is in part destroyed. This sectioning of a pebble will produce a sharp edge, and the upper contact of the caliche zone with the pebble represents the plane along which pebble sectioning by solution takes place.

All of the water falling on a pebble flows toward the margin. As it comes to the caliche rim some of it is turned laterally and flows along the edge. This concentration develops the marginal groove and at the same time creates the marginal rim. These are best developed in late mature and old age stages of morel structure. The origin of their initial development was described above, but their more pronounced development near the end of the cycle is not clear. It may be due in part to the fact that the drainage is essentially centripetal in the old-age stage. Water falling on the inner edge of the rim would flow toward the center of the pebble. Solution of the rim would be retarded by the less soluble caliche around its outer margin.

From this study, the marginal groove and rim appear to be limited to pebbles that originally had a convex surface, whereas pebbles with a flat original surface or limestone joint blocks would be characterized by a marginal rim surrounding a broad and somewhat shallow basin of the tinajita type.

CALICHE SHELL

Material taken in solution is first carried downward into the underlying material. After a rain storm, the hot desert sun quickly dries the surface, and upward migration of water is initiated. As evaporation occurs the originally dissolved substances are precipitated as caliche. Most of the deposition takes place at the base of pebbles. Bryan (1929) has pointed out that this is probably due to the fact that the rain did not cool the pebbles as quickly as the surrounding soil. Therefore, the temperature of the film of water around the base of the pebble is raised. This would increase the loss of carbon dioxide and thus increase the rate of precipitation. The first layer of caliche conforms to the outline of the pebble. Succeeding layers are deposited so that in its final stages it takes on the appearance of an inverted cone, composed of a series of shell-like layers. If a limestone pebble possessing this deposit is completely dissolved, a caliche shell may remain, and the inside of it will be concave with a smooth surface representing a mold of the original pebble. If the caliche is on the base of an insoluble pebble, it will become free only through mechanical action. Caliche shells are not uncommon in the Wind River locality, and it is believed that most of them represent deposits formerly on limestone pebbles that have been completely destroyed.

A chemical analysis of the caliche shows the following composition: CaO, 49.59 per cent; MgO, 0.77 per cent. Fe_2O_3 and SiO_2 not measured.

THE EVOLUTION OF MOREL STRUCTURE

GENERAL STATEMENT

The stages of a morel pattern constitute a process of chemical corrosion during which a pebble passes through a series of changes from its original form to complete

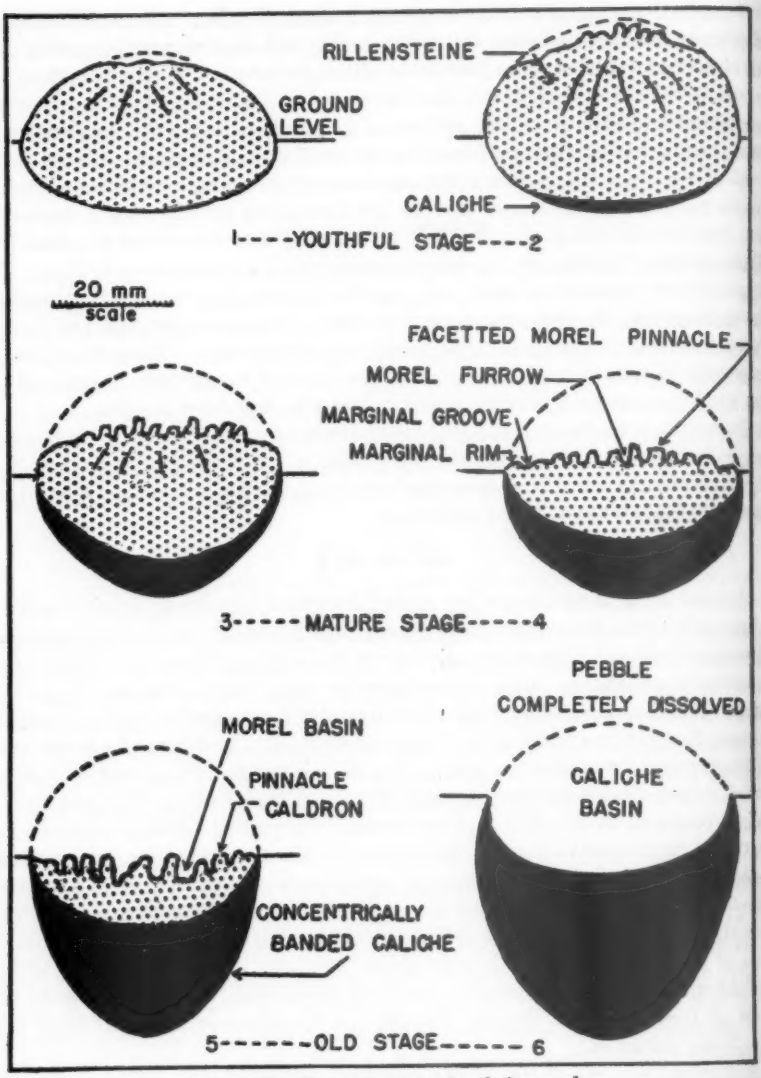

FIGURE 3.—*Stages of evolution in solution morel*

destruction. Corrosion is initiated as soon as the pebble is exposed at the surface. All observed morel pebbles occur as Pleistocene terrace gravels in a semiarid region. The conditions of drainage are excellent. Apparently the pebbles have been exposed for a relatively short period of time—several thousand years.

Unlike the development of lapies there is no repetition in the stages of morel evolu-

tion. Once corrosion is started evolution will continue until the pebble is completely destroyed, and a caliche shell is the only evidence of the existence of a former pebble.

STAGE OF YOUTH

The initial stage of morel presents a series of shallow pits, small pinnacles, and narrow ridges along the apex of the pebble. Furrows are not yet well devloped. Pinnacles and ridges are more likely to possess rounded or sharp tops rather than facetted surfaces. There is no evidence of morel basins or micronatural bridges. The steep lateral slopes of the pebble provides a surface over which water may flow downward. This results in the development of parallel rillensteine that may exetend from the caliche margin upward to embryonic pinnacles and pits. Small joints and thin calcite veins do not control the position of any of the major surface features. They extend through pits, pinnacles, and ridges alike.

Solution is more pronounced along the crest of the pebble than on the margins. There is no evidence of a boss as described by Bryan (1929). Apparently a boss could be developed only on a homogeneous limestone pebble. Any irregularities in chemical composition or physical properties would cause the initiation of a morel pattern and thereby prevent the development of broad facets. On the other hand, a rimmed facet might be developed on a pebble that had a somewhat flat original surface.

STAGE OF MATURITY

As the crest of the pebble is corroded downward, the surface area of the morel pattern increases until the greatest diameter of the pebble is reached. At this point in evolution the morel structure has attained its maximum complexity. It is characterized by an intricate system of furrows, ridges, and truncated pinnacles. The side walls of pinnacles are fluted, and caldrons have formed on the tops of some of them. A few of the pits have been enlarged into morel basins. Many of the side walls between pinnacles have become thin, and notches and micronatural bridges are common phenomena.

Because the pebble has been corroded downward or near its maximum exposed horizontal diameter, a marginal rim now exists. The great diversity in form of the mature morel pattern cannot be maintained for long. Further corrosion can result only in destruction of the pattern. When destruction starts old age is initiated.

OLD AGE STAGE

The floors of pits, furrows, and morel basins are lowered until they are below the marginal rim. At this stage drainage becomes centripetal; this represents a reversal in the direction of drainage from youth to old age. The basins are further lowered until they completely pierce the lower surface of the pebble and now rest on the inner surface of the caliche shell. The marginal rim is at the same time becoming thin and disappears at various places. Near the end only a few pinnacles will remain cemented to the inside of the caliche shell. Ultimately even these will be dissolved, and the caliche shell will remain as the end product in the evolutionary sequence.

CONCLUSIONS

The conditions necessary for the development of a solution-morel pattern are (1) convex surface, (2) impure nonhomogeneous limestone, and (3) arid to semiarid climate.

The development of inclined facets on pinnacles and ridges is attributed to a combination of two factors; (1) presence of a film of secondary calcite on the side walls, and (2) the irregular position of the upper edge of the film.

Pinnacles result from removal of the intervening side walls of ridges through the development of micronatural bridges and notches.

The morel furrows represent an interlocking system of U-shaped channels. These morel furrows were not developed on steep slopes and should not be confused with lapies. They are the result of a breakdown of walls surrounding pits initiated in the youthful stage. As the pits were enlarged intervening walls were destroyed, and a system of furrows and ridges with notches at various levels resulted.

No direct evidence is available concerning the rate of solution. The gravel-veneered terrace in which the morel pebbles were found is a remnant of a Pleistocene deposit. The terrace was formed during the Circle erosional cycle and is, therefore, pre-Bull Lake glacial stage. This places a maximum age on the gravels, but we cannot come very close to the number of years involved in the development of solution-morel structure; the best that can be said is that many thousands of years were required.

REFERENCES CITED

Blackwelder, Eliot (1915) *Post-Cretaceous history of the mountains of central Wyoming*, Jour. Geol., vol. 23, p. 307–340.

Bryan, Kirk (1927) *Ground water reconnaissance in Socorro County, New Mexico*, N. Mex. St. Eng., 7th Bienn. Rept., p. 81–82, 84–85.

——— (1929) *Solution-faceted limestone pebbles*, Am. Jour. Sci., vol. 218, p. 193–208.

Cjivic, Jovan (1924) *The evolution of lapies, a study in karst physiography*, Geog. Rev., vol. 14, p. 26–49.

Hoffmeister, J. E., and Ladd, H. S. (1945) *Solution effects on elevated limestone terraces*, Geol. Soc. Am., Bull., vol. 56, p. 809–828.

King, P. B. (1927) *Corrosion and corrasion on Barton Creek, Austin, Texas*, Jour. Geol., vol. 35, p. 631–638.

Laudermilk, J. D., and Woodford, A. O. (1932) *Concerning Rillensteine*, Am. Jour. Sci., vol. 223, p. 135–155.

Smith, J. Fred, Jr., and Albritton, Claude C., Jr. (1941) *Solution effects on limestone as a function of slope*, Geol. Soc. Am., Bull., vol. 52, p. 61–78.

Udden, J. A. (1914) *Flattening of limestone gravel boulders by solution*, Geol. Soc. Am., Bull., vol. 25, p. 66–68.

——— (1925) *Etched potholes*, Texas Univ., Bull. 2509, p. 5–9.

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FIGURES 1, 3. TOP AND SIDE VIEWS OF SPECIMEN IN EARLY MATURE STAGE.
Note truncated tops of pinnacles with light-colored marginal rim.

FIGURES 2, 4. TOP AND SIDE VIEWS OF SPECIMEN IN YOUTHFUL STAGE.
Note joints cutting across furrows and ridges. Initial development of marginal rim and groove.

FIGURES 5, 6. TOP AND OBLIQUE VIEWS.
Note joints cutting across furrows and ridges.

FIGURE 7. TOP VIEW OF SPECIMEN IN OLD AGE
Thin basal shell of pebble completely corroded along upper left margin.

SOLUTION MOREL LIMESTONE PEBBLES

FIGURE 1. QUARTZITE PEBBLE REMOVED FROM CALICHE SHELL

FIGURES 2, 4, 5. CALICHE SHELLS.
These may represent shells left after limestone pebbles have been completely corroded.

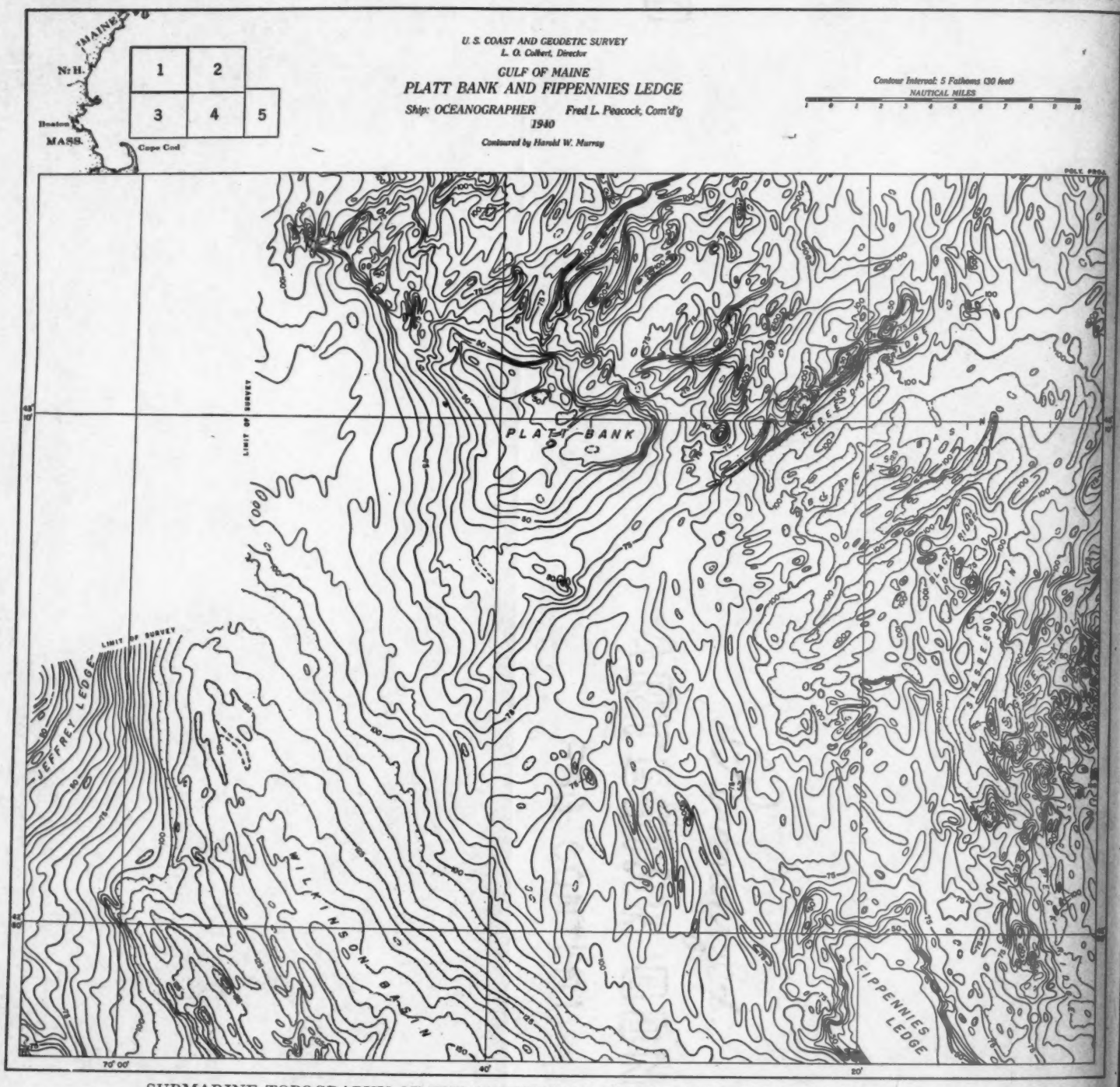
FIGURES 3, 6, 7. LIMESTONE, SANDSTONE, AND QUARTZITE PEBBLES WITH CALICHE BASES

SOLUTION MOREL LIMESTONE PEBBLES

FIGURE 1. TOP VIEW

FIGURE 2. OBLIQUE VIEW

MATURE SOLUTION MOREL



SUBMARINE TOPOGRAPHY OF THE VICINITY OF PLATT BANK AND FIPPENNIES LEDGE

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BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 58, PP. 153–196, 35 FIGS., 12 PLS. FEBRUARY 1947

TOPOGRAPHY OF THE GULF OF MAINE

FIELD SEASON OF 1940

BY HAROLD W. MURRAY

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12. Reduced portions of Veslekari fathograms of Rodgers Pass and Georges Bank ..... — At end of paper

ABSTRACT

A 1940 survey project of the U. S. Coast and Geodetic Survey Ship OCEANOGRAPHER commanded by Comdr. Fred. L. Peacock reveals a wealth of new information in the Gulf of Maine. This vessel was equipped with a visual fathometer and a graphic recorder fathometer operating simultaneously. Hydrography on a scale of 1:120,000 consists of 15,300 miles of sounding lines concentrated in an area of approximately 8900 square statute miles. Recorded soundings exceed 155,000. Physiographers now have valuable information to assist in solving the past history of this region including the role of continental glaciation.

The submarine relief is complex, with features rising from 50 to 500 feet above the floor of the Gulf. Cashe Ledge, the highest feature, rises 485 feet from the floor to within 25 feet of sea level. The basins are relatively broad and shallow, lying at depths of about 500 to 1000 feet. Base level of about two-thirds of the area surveyed is about 760 feet.

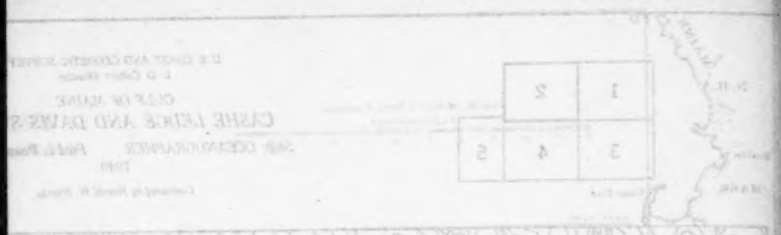
The basins have dual-bottoms, tentatively termed as "sediment" overlying the substrata. This sediment, ranging in thickness from a thin film to approximately 90 feet, is generally restricted to depths greater than 500 feet and is more prevalent in the deeper basins. The manner of its distribution is variable, but generally it smooths out irregularities. Anomalously, the sediment is sometimes absent in the deepest portion of a depression.

Emphasis is given to illustrations of sounding data. These consist of 5-fathom interval contour maps of the surveyed area and 231 representative fathogram profiles covering features of interest. The latter illustrate 1500 statute miles of graphic recorder sounding lines.

INTRODUCTION

Hydrographic investigation of the Gulf of Maine was undertaken by the U. S. Coast and Geodetic Survey between 1854–1875 (Table 1). This development

SUBMARINE TOPOGRAPHY OF THE VICINITY OF CASHE LEDGE AND DAVIS SWELL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consisted of sounding lines designed to explore the relief of the Gulf in general and to define in particular those prominent features then known to exist, such as Cashe, Fippennies, and Jeffrey Ledges, and Georges, Jeffrey, Platt, and Stellwagen Banks. Many of these soundings were accompanied by bottom samples and temperature data. These observations are of permanent value because relatively few such observations are made in modern echo sounding.

TABLE 1.—*Former U. S. Coast and Geodetic Survey expeditions in the Gulf of Maine*

Year	Hydrographic sheet	Vessel	Commanding Officer
1854–56	H—440	Bibb	Lt. H. S. Stellwagen
1857	H—593	Bibb	Lt. C. R. P. Rodgers
1858–59	H—700	Bibb	Lt. Alexander Murray
1860	H—861	Vixen and Corwin	Lt. T. S. Phelps
1860	H—1305	Bache	Lt. John Wilkinson
1872–74	H—1207a & b	Blake	Comdr. J. A. Howell
1874	H—1304	Bache	Acting Master Robert Platt
1875	H—1303	Blake	Lt. Comdr. C. D. Sigsbee

A perusal of the literature of this region reveals that considerable thought has been given to the results of these surveys. Johnson (1925) published a series of composite profiles using practically all of the soundings charted from this older work. Had the present detailed surveys been available, the early investigators might have been able to work out with a greater degree of assurance the physical history of this region, including the effect of continental glaciation.

SOUNDING METHODS

OFFSHORE HORIZONTAL CONTROL

The horizontal control of surveys in this region was furnished by the U. S. Coast and Geodetic Survey's radio acoustic-ranging methods (Peacock, 1940; Rude, 1944). The initial problem was to establish a base line, out of sight of land, and in this instance a line about 34 miles long and 24 miles offshore was established (Fig. 1, line HOT-QUE). This base line trended northward along the east side of Stellwagen Bank and Jeffrey Ledge and fronted the west side of the area to be surveyed. The second step in this pattern was to establish precisely the geographic positions of buoys ANT and FAD. These were located by repeated sextant angles to prominent landmarks and lighthouses along the coast in the vicinity of Cape Ann and Portsmouth. From these two points, lines were extended to the extremities of line HOT-QUE. The length and direction of these three lines were then measured and controlled by taut-wire and sun-azimuth observations. Using the base line as one side, a system of similarly controlled geometric quadrilaterals, interconnected and strengthened by diagonals, was extended about 110 miles offshore.

In general, the area within a single quadrilateral was completely surveyed as a unit. The anchor buoys within the area sounded were then picked up and placed on the extremities of new geometric figures. Thus, the various quadrilaterals were formed and extended with a limited number of firmly controlled sono-radio buoys. Thus the

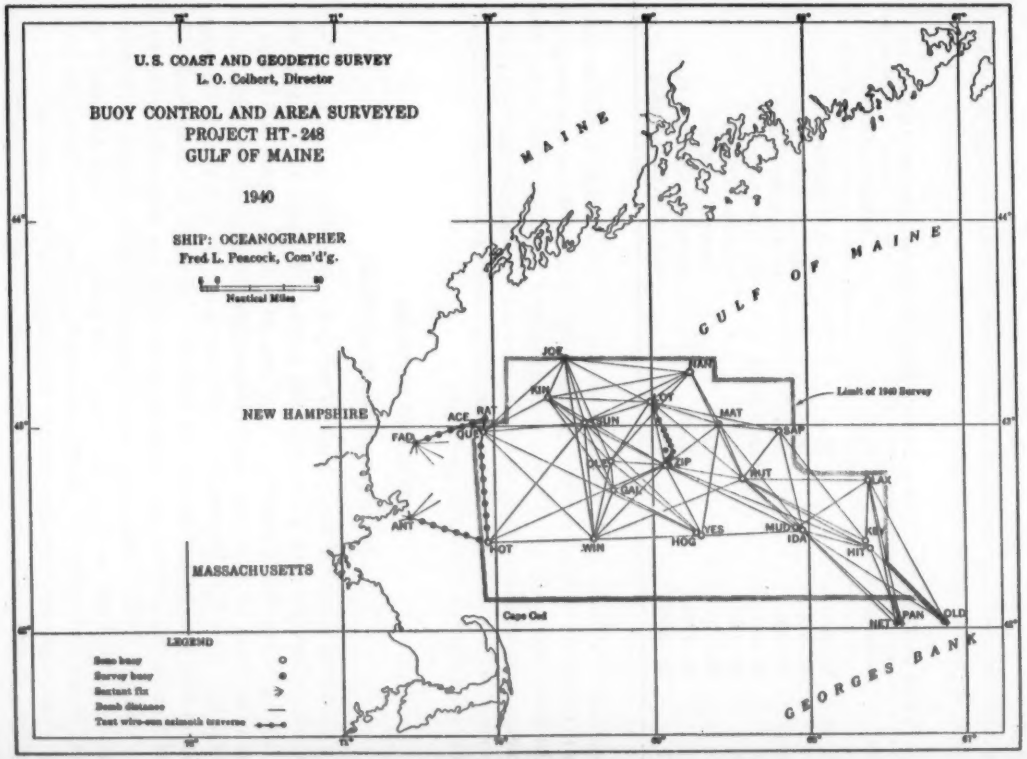


FIGURE 1.—*Sono-radio buoy control data*
(After F. L. Peacock)

system of sono-radio control points defining the several quadrilateral systems was horizontally controlled, extended eastward as units, and was not at any one time in place entirely as shown in Figure 1.

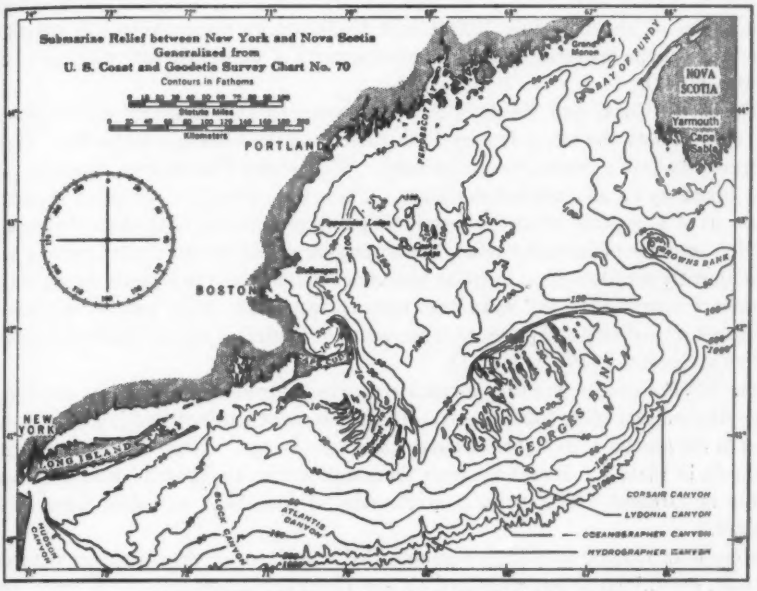


FIGURE 2.—*Submarine relief off the New England Coast*
(After Paul A. Smith)

FIGURE 1.—*Sono-radio buoy control data*
(After F. L. Peacock)

Considered as a whole, the quadrilateral figures appear to be unduly complex. This resulted from problems encountered on the working grounds by the Commanding Officer. For example, buoy KIN was established on Platt Bank to strengthen the control on the northwest, as distance determinations from buoy SUN were too long or otherwise unsatisfactory. Buoys YES, IDA, HIT, and PAN were re-established points of control occasioned by storms and a hurricane which swept over the working grounds during the season.

INTENSITY OF SOUNDING LINES

Sounding lines on the 1:20,000-scale surveys were generally spaced at intervals of about a mile over moderate bottom relief. In areas of irregularity, the spacing was reduced to half a mile, as when over flat-topped Fippennies Ledge, or a quarter of a mile or closer when over areas rising nearer the surface. When necessary, an additional system of sounding lines was run parallel to the major axis of the feature, or at an angle to the main spacing, as in the case of Sigsbee Knoll.

The immediate vicinity of Cashe Ledge was developed separately on a scale of 1:20,000. These lines were spaced about 100 to 400 meters apart. Positions were controlled by 3-point sextant fixes on supplementary buoys established by a taut-wire, sun-azimuth control (Fig. 1, line LOT-ZIP).

SOUNDING EQUIPMENT

Soundings on this project were obtained with a visual Dorsey Fathometer No. III, an 808 Recording Fathometer, and a Hughes Veslekari Graphic Recorder. These instruments have directional properties and are individully designed for supersonic frequencies of about 17,500, 20,000, and 16,000 cycles respectively. A complete discussion of the operational and technical aspects of these instruments is given by Adams (1942).

The U. S. Coast and Geodetic Survey's vessel OCEANOGRAPHER was equipped (Pl. 6) with both the visual Dorsey Fathometer and the Veslekari Recorder. These instruments were operated simultaneously. The Dorsey Fathometer, however, was used primarily for all recorded soundings. These were usually observed at standard intervals of 30 seconds when the vessel was passing over areas of moderately smooth relief. In areas of irregular relief, the hydrographer decreased these intervals and subsequently supplemented them by soundings taken from the graphic record of the Veslekari instrument. All soundings were corrected for draft, velocity of sound, temperature, salinity and pressure of sea water. Typical Veslekari Recorder fathograms are shown in Plates 8 to 12.

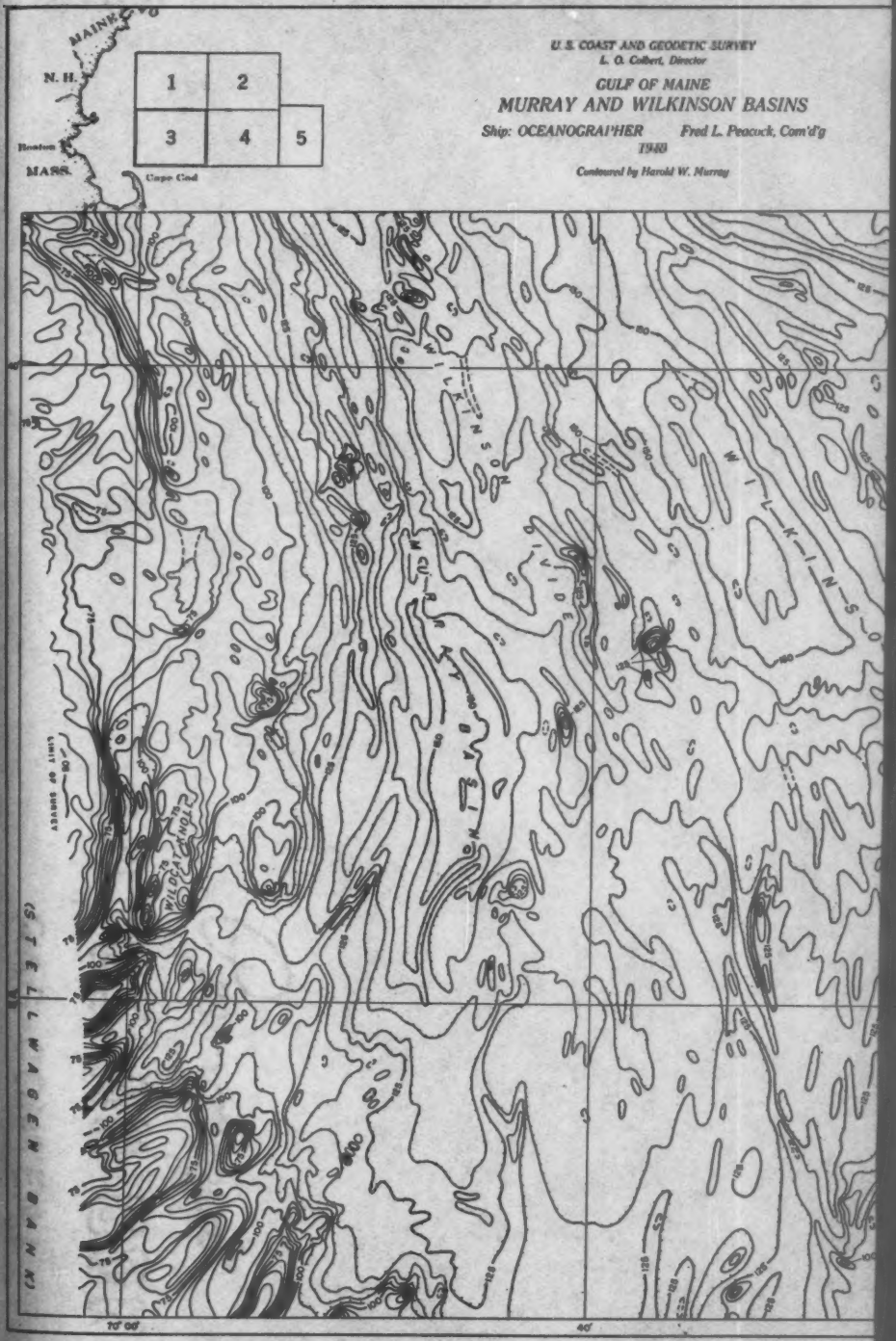
The 808 Fathometer is a semiportable recording instrument designed for surveying in depths not exceeding 160 fathoms. This instrument was installed in a launch and used in the special 1:20,000 scale survey of Cashe Ledge. A typical 808 fathogram is shown in Plate 7. Soundings from these fathograms are in units of fathoms and sixths of fathoms. This permits contouring of soundings at 1-foot intervals if desired.

More than 155,000 soundings were recorded in this work. In areas over soft mud bottom, the thickness was measured on the Veslekari fathograms at the same time interval as the recorded soundings and plotted on the final smooth sheet. The thicknesses are tabulated for about 35,000 additional soundings. No estimate can be made of additional soundings which can be obtained if desired at a later date from the graphic recorder fathograms.

INTERPRETATION OF FATHOGRAMS

Graphic recorder profiles are termed "fathograms". These are true profiles only when a perfectly horizontal bottom is recorded. Fathograms are composite returns of all echoes received from suitable reflecting surfaces as the vessel passes on its course. Hence, the first echo return represents only the shortest distance and is registered as the apparent least depth beneath the vessel. The succeeding echoes are likewise registered at later instants and tend to build up the lower thickness of the profile trace. Frequently some of the echoes are superimosed in separate groups or series and indicate additional features off to one side of the vertical. Supersonic frequencies penetrate and are reflected from sand, mud, or other loose material, and indicate bodies of heavily silt-laden waters or waters of varying densities as well as the underlying subsurface. These phenomena further complicate the evaluation of the fathogram details and the ascertaining of the least depths.

Supersonic directional frequencies possess distinct advantages over ordinary sonic frequencies when used to obtain sounding data. Not the least of these is the ability



SUBMARINE TOPOGRAPHY OF THE VICINITY OF MURRAY

U. S. COAST AND GEODETIC SURVEY
L. O. Colbert, Director

GULF OF MAINE
MURRAY AND WILKINSON BASIN

Ship: OCEANOGRAPHER Fred L. Peacock, Co
1948

Contoured by Harold W. Murray

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NAUTICAL MILES
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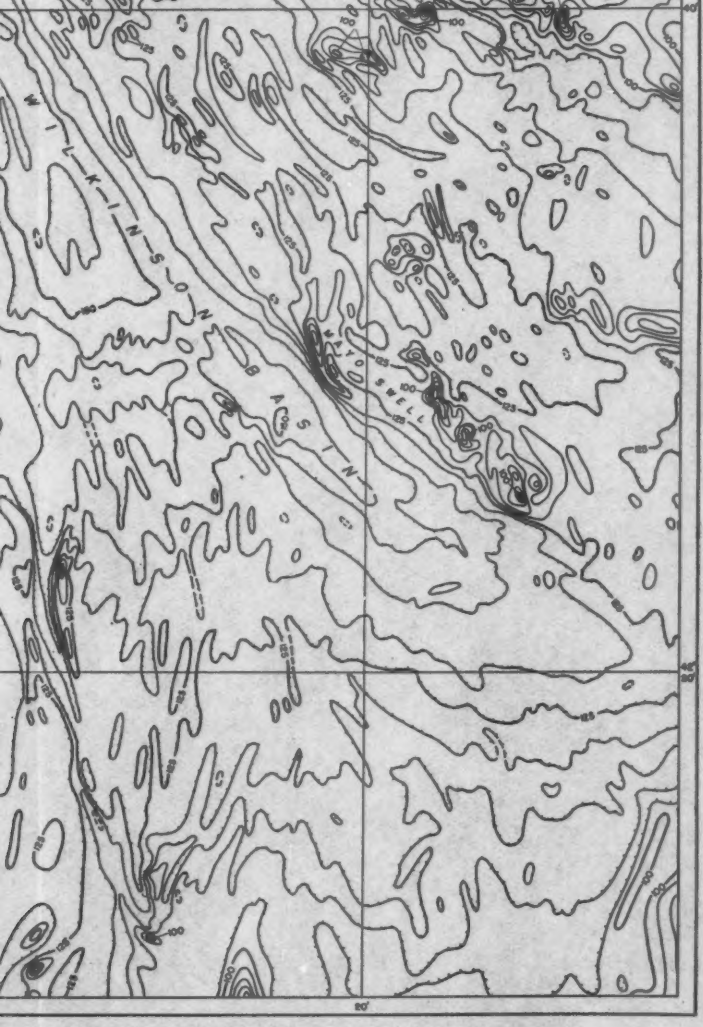


Y OF MURRAY AND WILKINSON BASINS

to focus the outgoing signal energy in a comparatively narrow beam. This beam is approximately cone-shaped, has a diameter of about 30 degrees, and reduces side echoes. However, as the depth of the water increases, so does the radius of the scanning cone, and consequently the width of the area sounded is increased. The scanning radius for depths encountered in the present project are shown in Table 2.

TABLE 2.—*Scanning radius of a 30-degree diameter cone*

Depth (Fathoms)	Scanning radius (Meters)	Depth (Fathoms)	Scanning radius (Meters)
25	12	125	61
50	25	150	74
75	37	175	86
100	49	200	98

A convenient thumb rule to remember is that "one-half the depth in fathoms equals the scanning radius in meters."

Accompanying this paper are 231 fathogram profiles comprising a total of about 1500 statute miles of sounding lines. These are single-line tracings of the Hughes Veslekari Recorder fathograms. (*Compare* Plate 10 with Figure 22.) These compiled illustrations are referred to here as fathogram profiles to distinguish them from the original fathograms.

In preparing the fathogram profile illustrations, as many profiles as possible were shown in a given illustration. Referring to Ammen Basin (Fig. 3) a series of 13 parallel reference lines, including the top and bottom margin of the border of the illustration, were drawn at intervals equal to 50 fathoms of depth in a vertical plane. Since the 10 profiles selected for this illustration have minimum depths of about 95 fathoms and maximum depths of about 135 fathoms, the nearest reference line passing through a portion of the profiles or just above the profiles is the 100-fathom line. The legends (as profile A,) at the left side of the illustrations represent the numbers of the individual profiles. The zero-reference lines or sea level for these respective profiles are noted on the right side of these illustrations (as Sea Level A). Occasional depth values have been appended to the profiles to facilitate referencing.

The vertical-scale exaggeration of a fathogram varies with the speed of the boat. The vertical scale of the Hughes Veslekari fathograms used chiefly as illustrating material in this paper is about 14 times the horizontal scale. The vertical-scale exaggeration of the 808 fathogram in Plate 7 is about 35 times the horizontal scale.

GEOGRAPHIC NAMES

Geographic names of this region fall in three categories. A few old and well-established names go back to early days; Browns Bank, Cashes Ledge, and Jeffreys Ledge are found on a map in the English Pilot of 1761. The spelling of these older names differs considerably, one of them appearing as Jeffereys, Jeffreys, Jefferys, and Jeffry, and all of them being used variously with and without a final "s" or "s". For example, Brown Bank would be correct if the adjective is descriptive, but if a family name is involved, as of its discoverer, then it should be Browns Bank. The

word Cashe might also have a double meaning, although in written form the final "e" eliminates this possibility. The form Platt instead of Platts Bank follows established usage, in that Platt was a naval officer on a vessel engaged in surveying this area in 1875. All of these older names were referred to the U. S. Board on Geographical Names in 1941, but, pending the adoption by that Board of correct official spellings, these names will probably continue to show varying usage on the charts and maps of the Gulf of Maine.

The second category of names includes uncharted names used by fishermen who frequent this area. A map compiled by Rich (1929) shows many such names of formations known in part at least to these fishermen, but which have never been placed on the nautical charts nor attained general acceptance.

The third category includes numerous distinctive features accurately revealed for the first time which necessitates the assignment of new names. These new names should preferably have historical value or be suitably descriptive. *Three Dory Ridge*, an excellent choice of the local fishermen, has been retained, but *Big Ridge*, lacking in distinctive character, has been replaced by *Parker Ridge*. In general, the previously assigned generic terms have been kept when appropriate, but the proper names used with them are those of persons, selected from a list of deceased hydrographers and their associates who jointly assisted in the exploration of this region during the years 1854–1875 (Table 1).

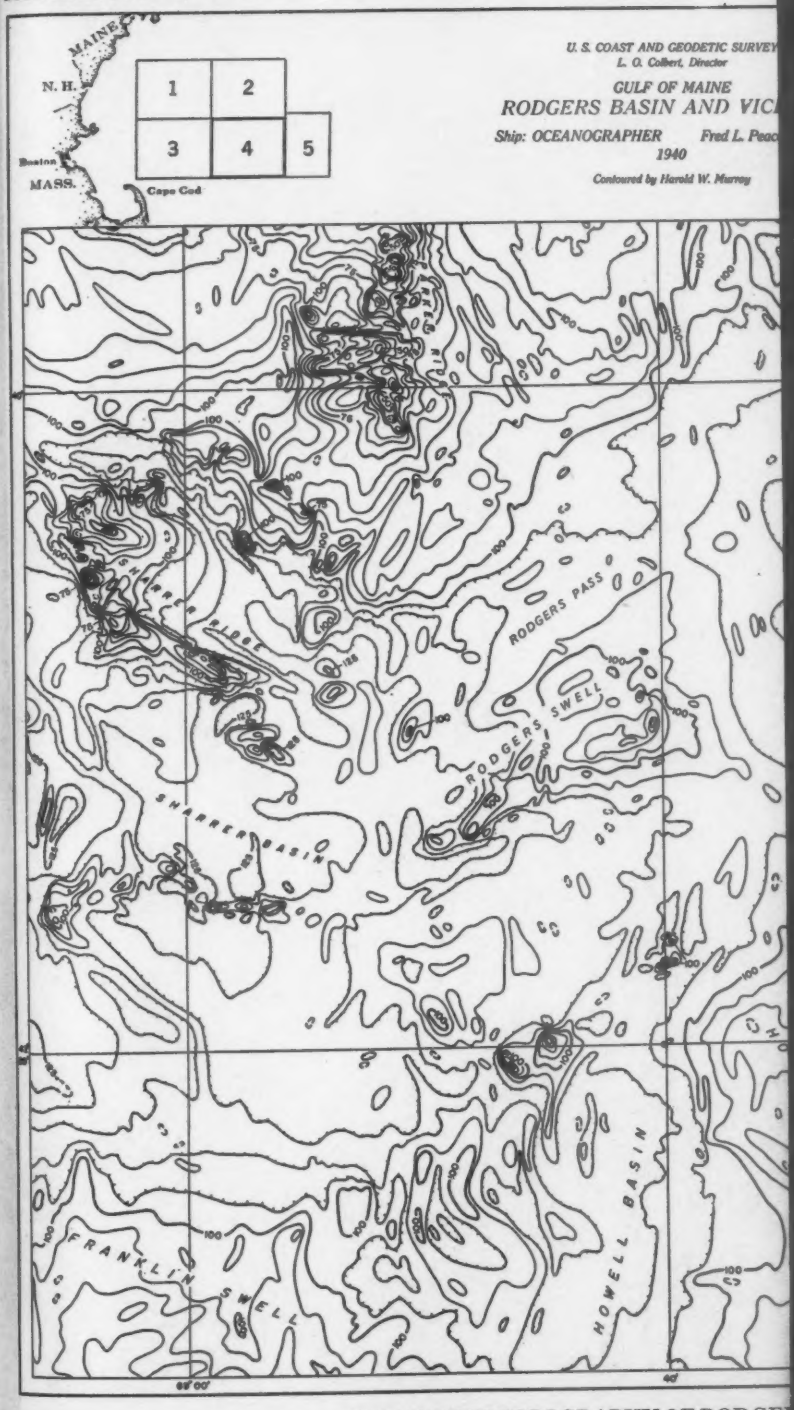
The generic terms bank, ledge, and ridge have been previously applied in this region with no apparent physiographic distinction, as in the case of the old established names of *Platt Bank* and *Fippennies Ledge*, two truncated features possessing considerable similarity. Features along the margins of the present survey project have been left unnamed, pending further data defining more completely their shapes and dimensions.

TOPOGRAPHY OF THE GULF OF MAINE

Relief in the surveyed portion of the Gulf of Maine consists of numerous banks, knolls, ridges, swells, and basins (Pls. 1–5). The dimensions of the prominent basins and features of elevations are listed in Table 3. Representative fathogram profiles and larger-scale contour maps of local features are shown in Figures 3 to 35 inclusive.[1]

The most singular feature of this region is the extensive basin area radiating south and southeast from Jeffrey Ledge (Pls. 1, 3). Wilkinson Divide separates this feature into two parts. Murray Basin on the west side is slightly smaller, having a maximum depth of 156 fathoms. Wilkinson Basin, trending southeast, has a maximum depth of 161 fathoms, the greatest depth obtained in this region. The maximum depth of 183 fathoms formerly cited in literature of this area (Johnson, 1925; and others) is 22 fathoms deeper. This depth, obtained in 1860, is slightly too great, probably because of the difficulty of obtaining a true vertical lead-line sounding

[1] Readers desiring to study this region in greater detail should obtain copies of the U. S. Coast and Geodetic Survey Charts Nos. 1106 and 1107. These charts are on a scale of about 1:385,000. They show representative soundings in black, and 10-fathom contours overprinted in blue. Chart No. 1106 covers most of the Gulf of Maine including the present survey project. Chart No. 1107 covers the Georges Bank region on the south.



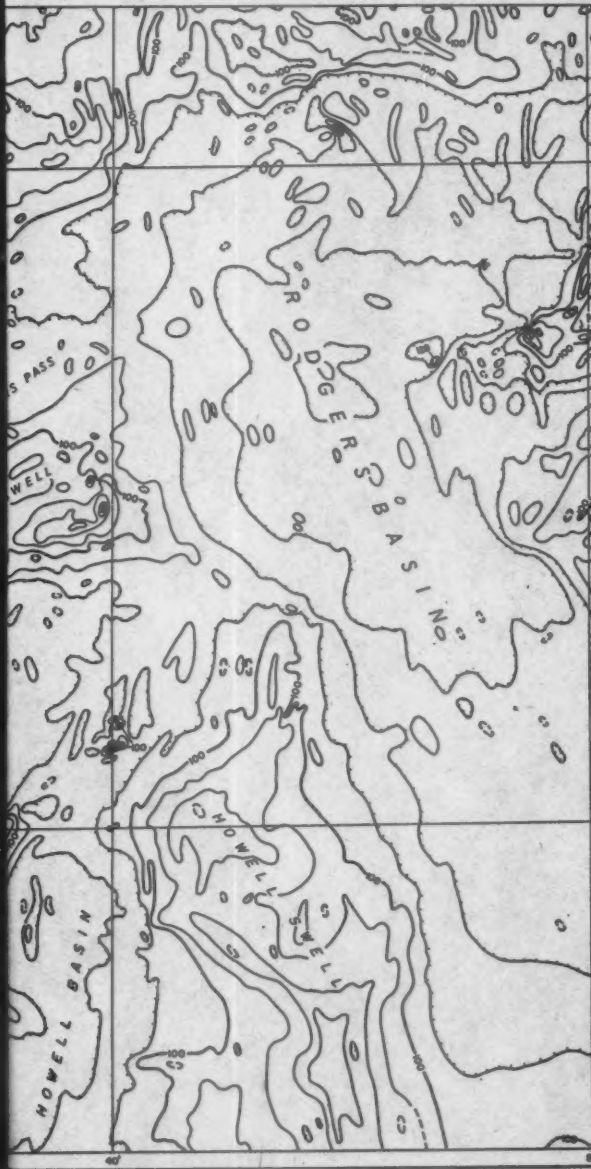
SUBMARINE TOPOGRAPHY OF RODGE

U. S. COAST AND GEODETIC SURVEY
L. O. Colbert, Director

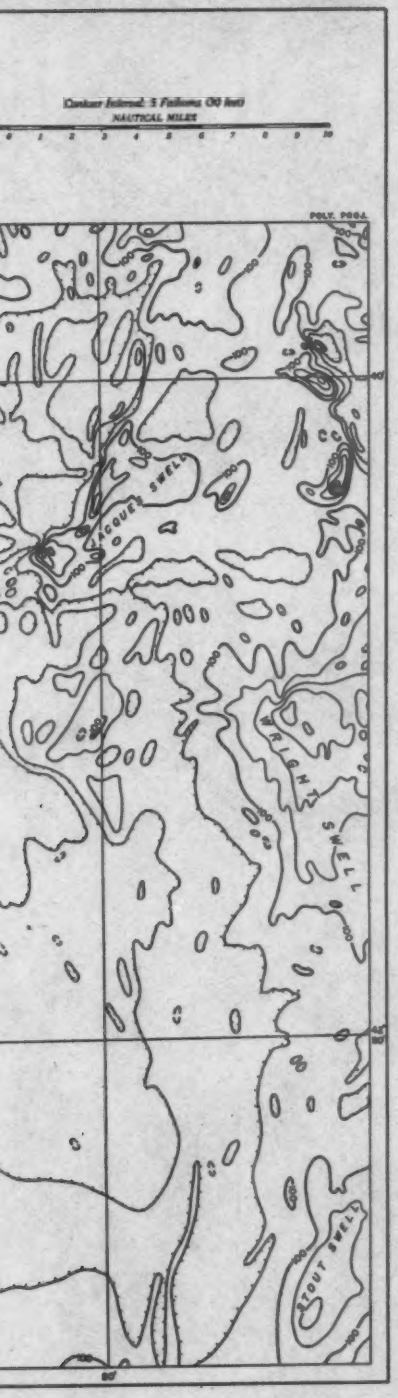
GULF OF MAINE
GERS BASIN AND VICINITY

CEANOGRAPHER Fred L. Peacock, Com'd'g
1940

Contoured by Harold W. Murray



GRAPHY OF RODGERS BASIN AND VICINITY


Contour Interval: 5 Fathoms (30 feet)
NAUTICAL MILES
0 1 2 3 4 5 6 7 8 9 10
POLY. PROJ.
SEGUE SWELL
WRIGHT SWELL
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at such depths. The discrepancy is due to the indeterminate catenary of the sounding wire caused by currents and the drifting of the sounding vessel.

TABLE 3.—*Dimensions of principal features in the Gulf of Maine*

A. BASINS

Feature	Threshold depth (Fathoms)	Approx. max. dimensions		Deepest sounding (Fathoms)	Relative height (Feet)
		Breadth (Miles)	Length (Miles)		
Ammen Basin	105	6	22	132	162
Blacks Basin	95	5	12	126	186
Cashe Basin	90	7	17	118	28
Davis Basin	105	8	13	124	114
Howell Basin	110	6	10	121	90
Lindenkohl Basin	125	6	9	131	36
Murray Basin	140	7	30	155	90
Rodgers Basin	110	14	29	125	90
Sharrer Basin	120	9	9	133	78
Sigsbee Basin	105	3	9	127	132
Truxton Basin	110	5	12	127	102
Wilkinson Basin	140	10	41	161	126

B. FEATURES OF ELEVATION

Feature	Threshold depth (Fathoms)	Approx. max. dimensions		Least depth (Fathoms)	Relative depth (Feet)
		Breadth (Miles)	Length (Miles)		
Ammen Swell	100	7	19	79	126
Blacks Ridge	100	3	8	66	204
Cashe Ledge	*85	7	33	41/2	485
Davis Swell	95	5	19	65	180
Fippennies Ledge	75	7	15	37	258
Jacques Swell	100	3	6	83	102
Lindenkohl Knoll	*110	4	9	87	78
Mayo Swell	*120	2	10	93	162
Peck Ridge	*75	2	9	47	168
Platt Bank	75	13	21	29	276
Rodgers Swell	105	6	10	78	162
Sewell Swell	*100	5	22	89	66
Sharrer Ridge	*100	4	8	66	204
Sigsbee Knoll	*85	5	11	40	270
Three Dory Ridge	85	1	11	42	258
Wright Swell	100	8	21	79	126

* Curve does not enclose entire features.

Platt Bank and Fippennies Ledge (Pls. 1, 2) are similar in several respects. Both have truncated tops which are approximately parallel to sea level. The least depths are 29 and 37 fathoms respectively, a difference of only 8 fathoms. The flattened area enclosed by the 35-fathom curves on Platt Bank is about 9 square miles. The 40-fathom curve outlining the summit of Fippennies Ledge encloses about 14 square miles. The major trend lines are northwest-southeast except that Platt Bank is triangular in outline. The slopes fronting Wilkinson Basin are smooth. The relief fronting the northeast side of Platt Bank consists of a series of northeast-trending ridges and basins.

Three Dory Ridge (Pl. 1) is in line with the southern leg of the Platt Bank triangle. Its distinctive name was applied by local fishermen because of the three detached

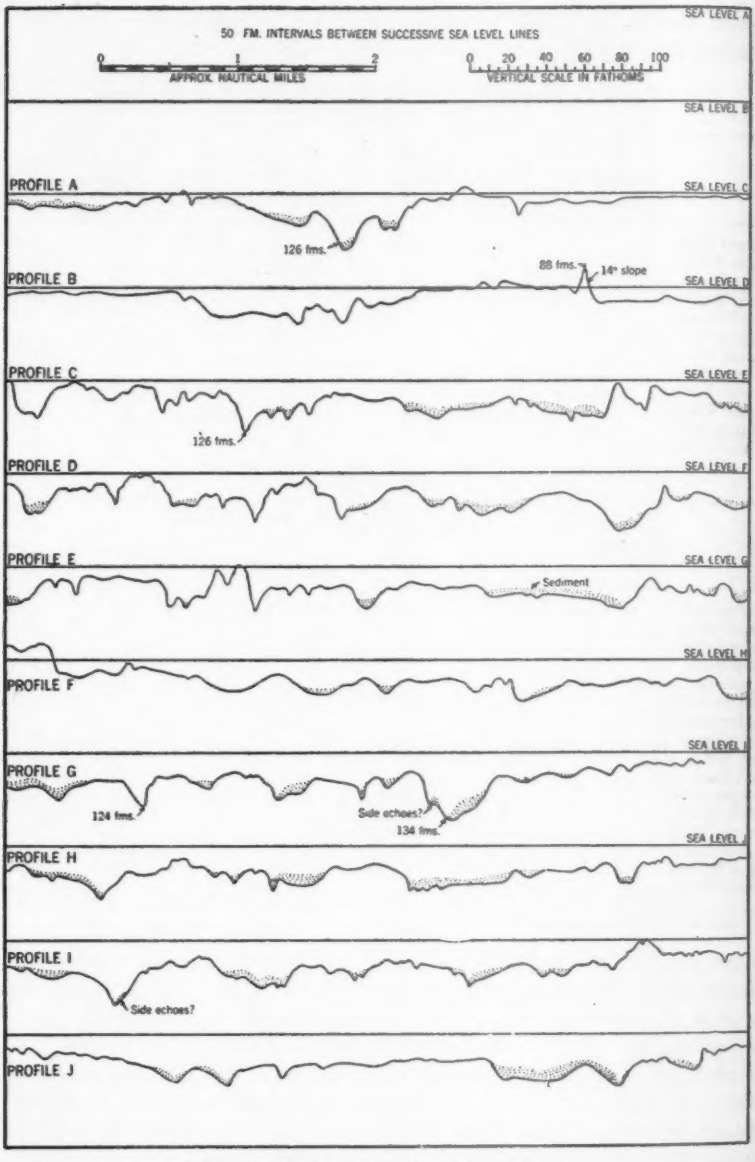
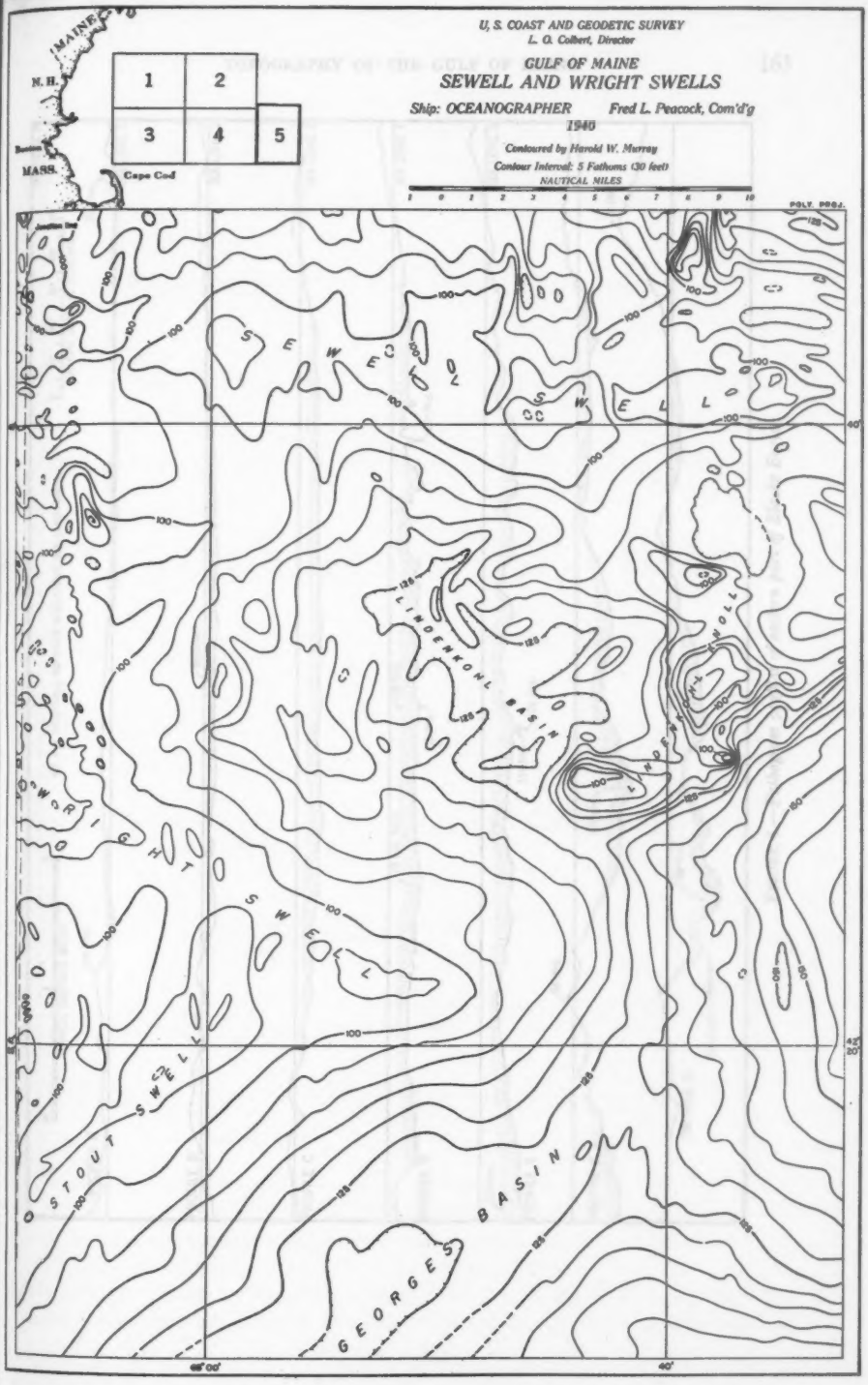


FIGURE 3.—*Fathogram profiles of Ammen Basin*

knolls with minimum depths of 42, 48, and 49 fathoms. Blacks Basin is somewhat uneven. The 100-fathom depression contour here encloses Blacks Basin, Blacks Ridge, and Sigsbee Basin.



SUBMARINE TOPOGRAPHY OF THE VICINITY OF SEWELL AND WRIGHT SWELLS

SCHMARRK, TOPOGRAPHY OF THE VICINITY OF SEWELL AND WRIGHT SWELLS

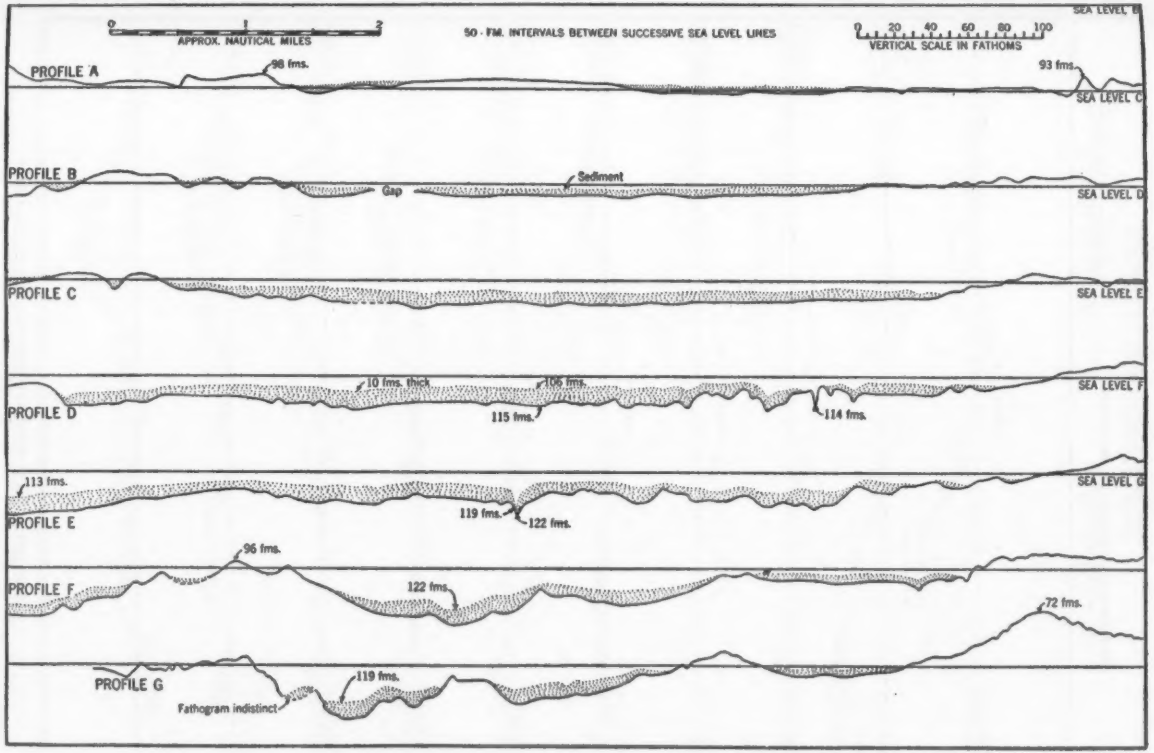
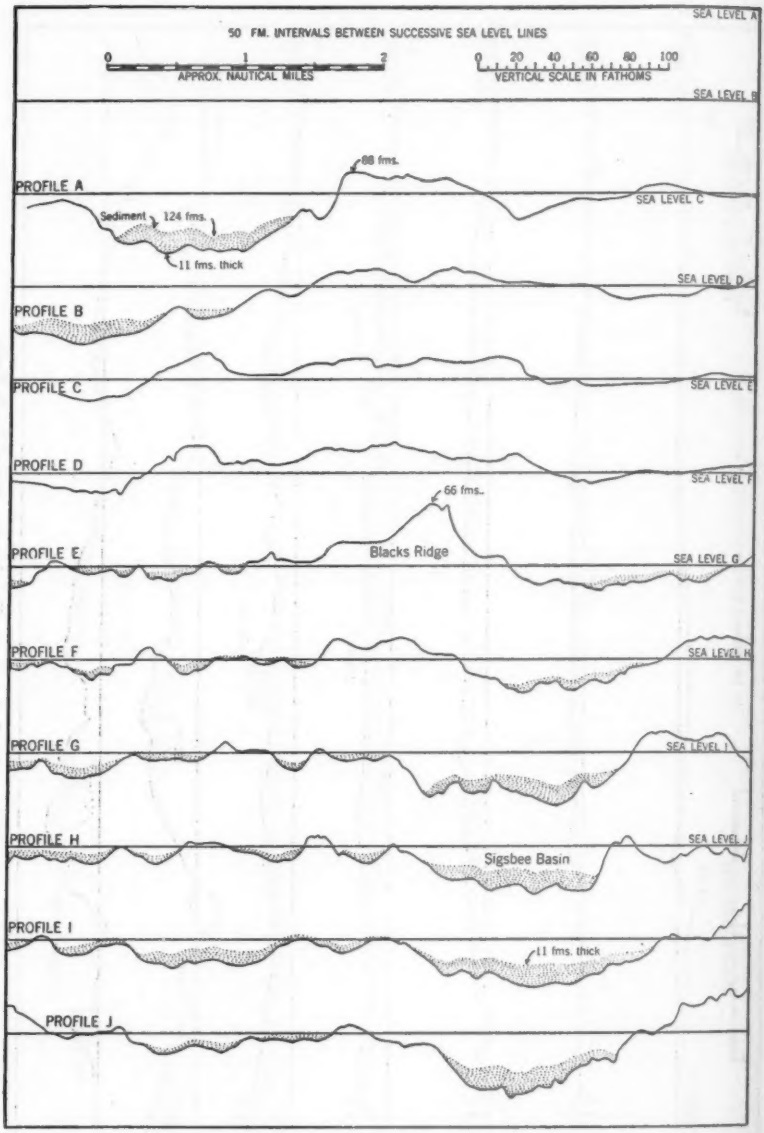


FIGURE 4.—*Fathogram profiles of eastern part of Blacks Basin*



Fathogram profiles of Blacks Ridge and north portion of Sigsbee Basin

FIGURE 5.—*Fathogram profiles of Blacks Ridge and north portion of Sigsbee Basin*

Cashe Ledge (Pls. 2, 4) is a focal point in the Gulf of Maine proper. Peck Ridge, Sigsbee Knoll, Cashe Ledge, and Parker Ridge appear to be one contin-

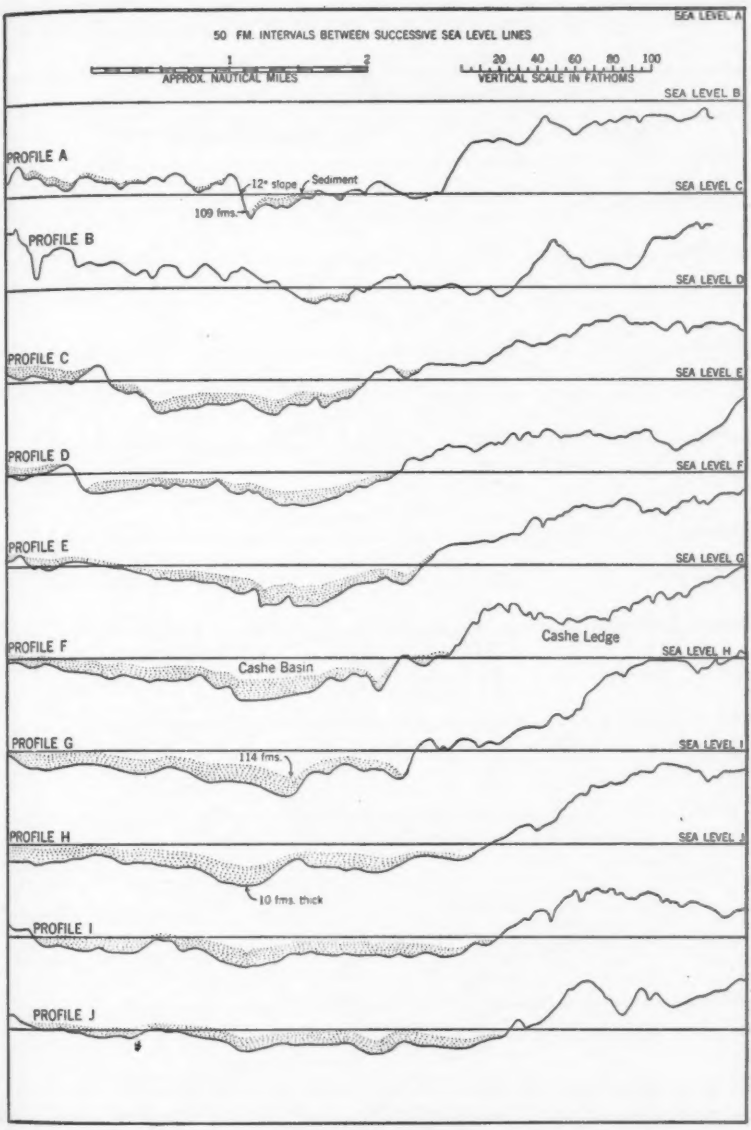


FIGURE 6.—*Fathogram profiles of Cashe Basin and west side of Cashe Ledge*

uous feature arranged like a horseshoe and enclosed principally by the 80-fathom curve. Most of the knolls within this curve rise to within less than 50 fathoms of the surface. In the vicinity of Cashe Ledge they reach nearer the surface,

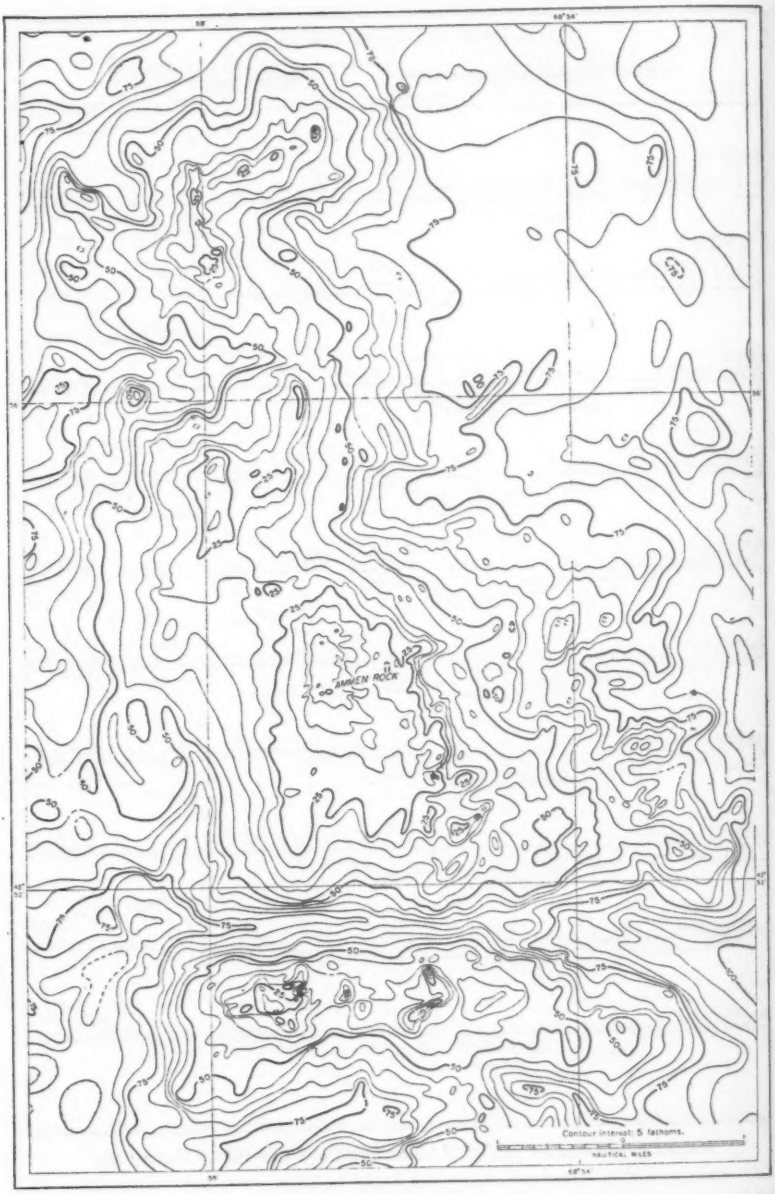


FIGURE 7.—*Contours of Cashe Ledge*

and, in the case of Ammen Rock, rise within 4¼ fathoms or 25 feet of the surface. This rock, kelp-covered, is an offlying menace to navigation.

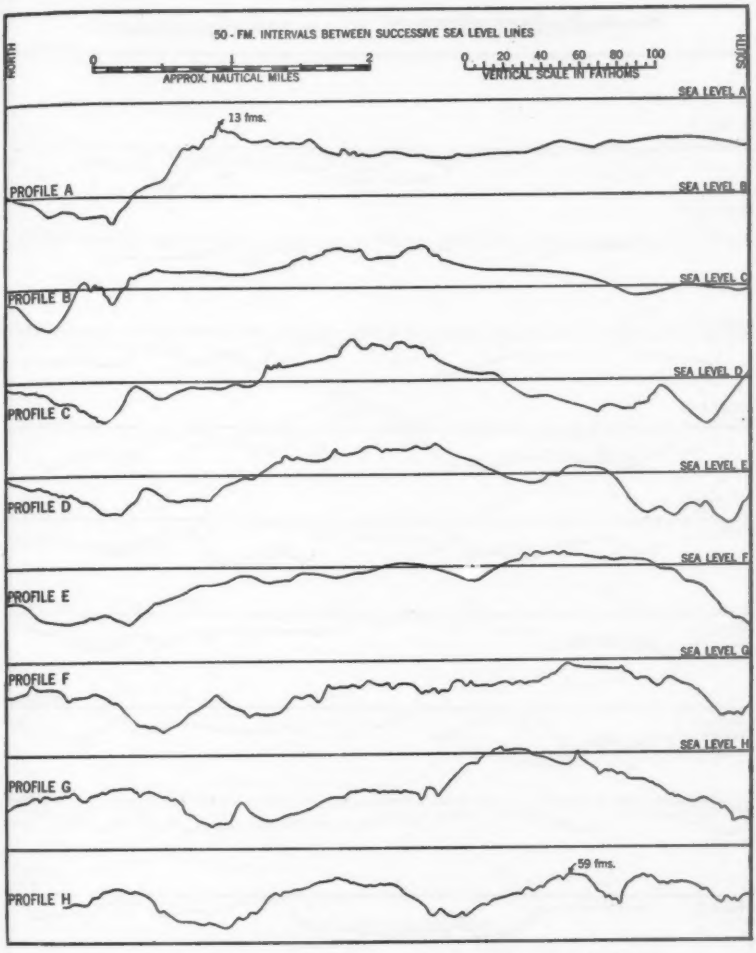


FIGURE 8.—*North-south fathogram profiles of west side of Cashe Ledge*

To the east of the Cashe Ledge vicinity (Pl. 2), Ammen Basin, Ammen Swell, Davis Basin, Davis Swell, and Truxton Basin are characterized by considerable irregularity. Davis Swell is the highest and rises within 65 fathoms of the surface. The east-west trend of this feature is at variance with the approximate north-south trends of the adjacent features.

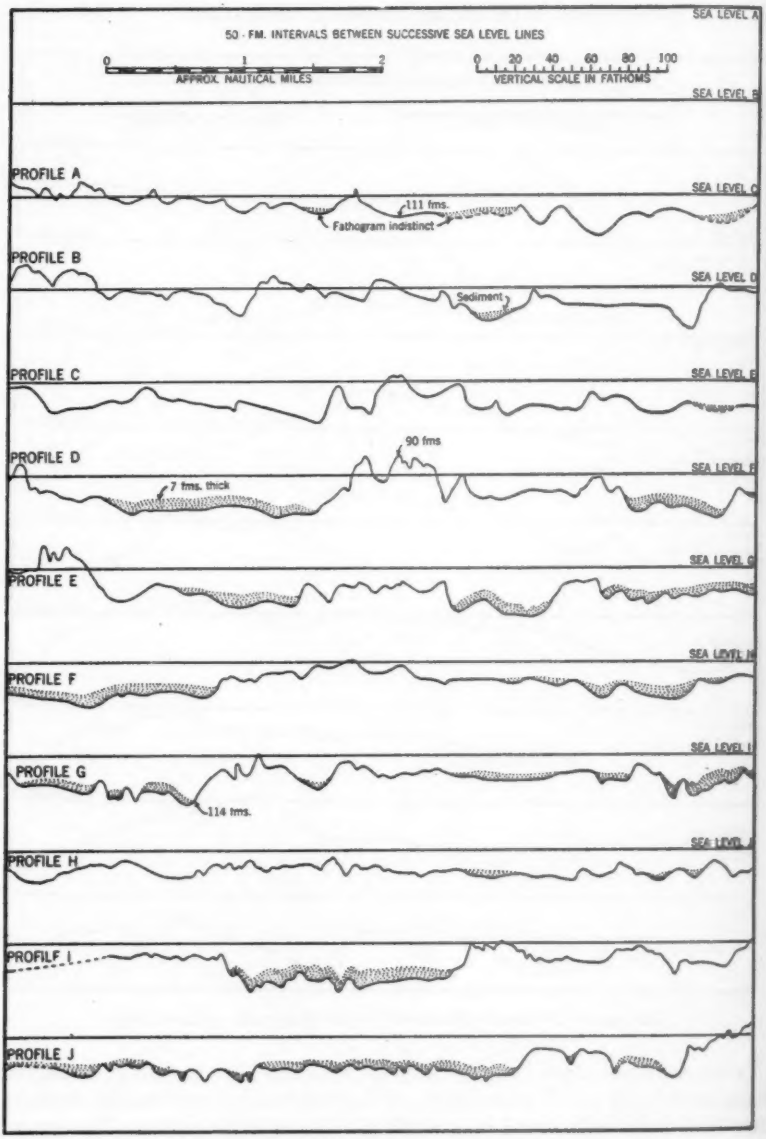


FIGURE 9.—*Fathogram profiles of Davis Basin*

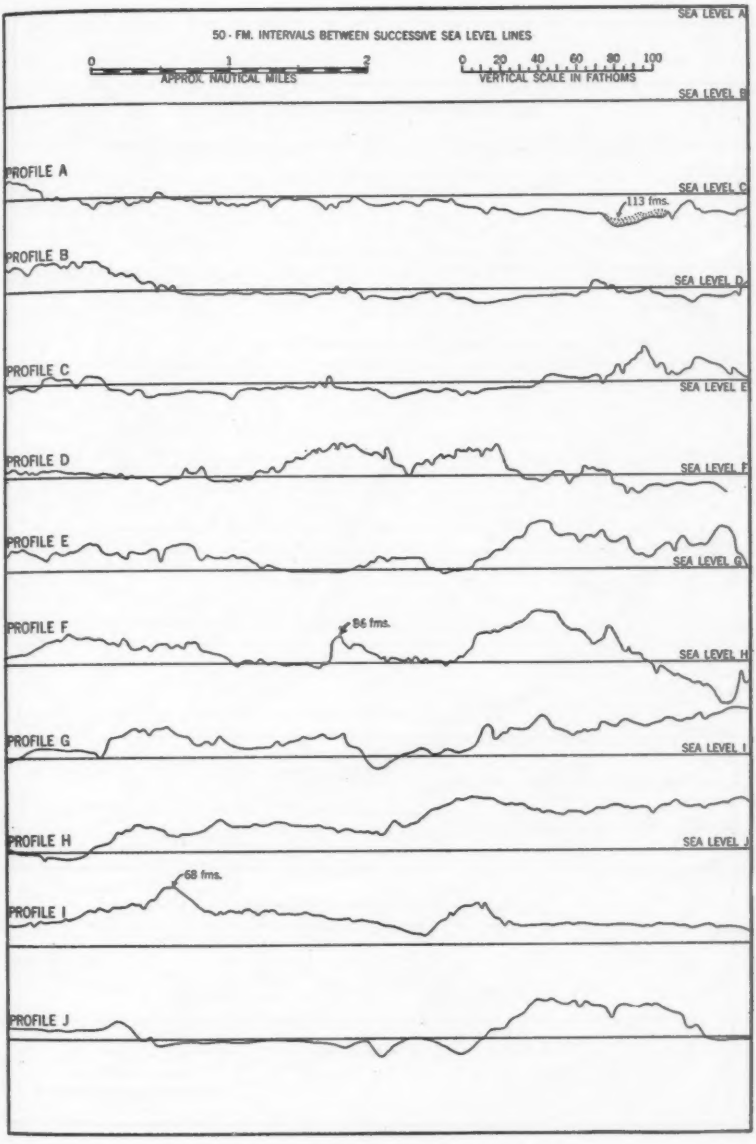


FIGURE 10.—*Fathogram profiles of Davis Swell*

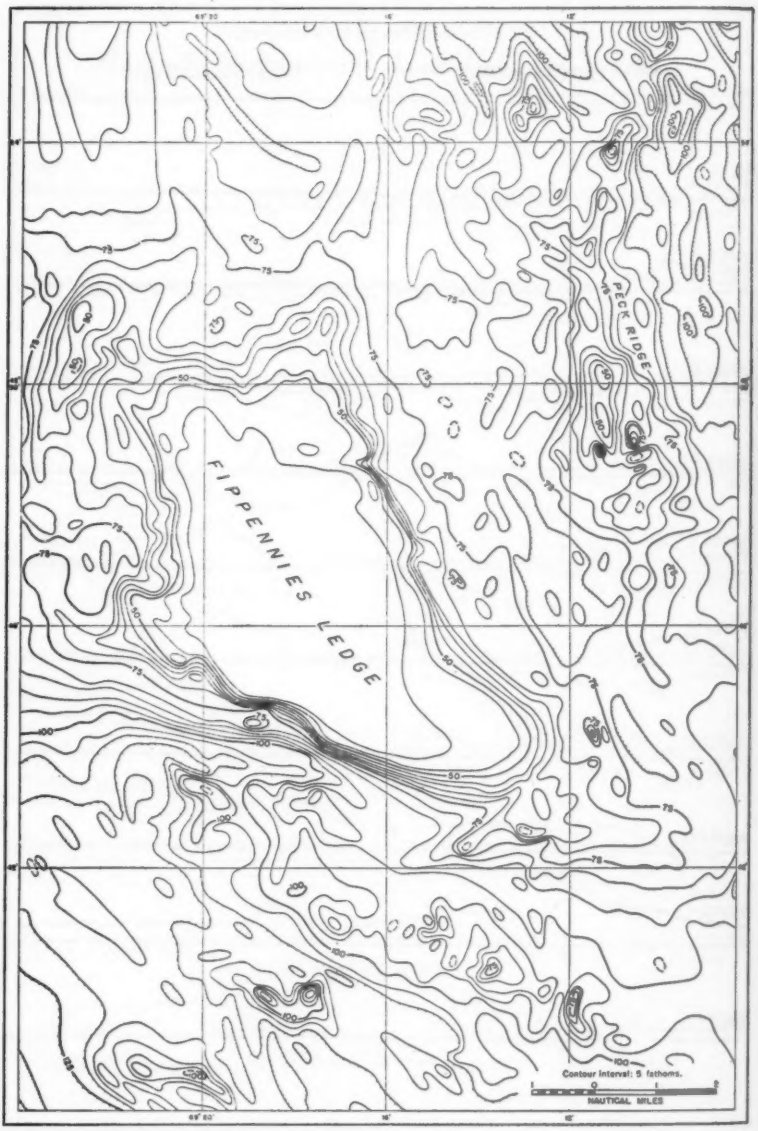


FIGURE 11.—*Contours of Fippennies Ledge and Peck Ridge*

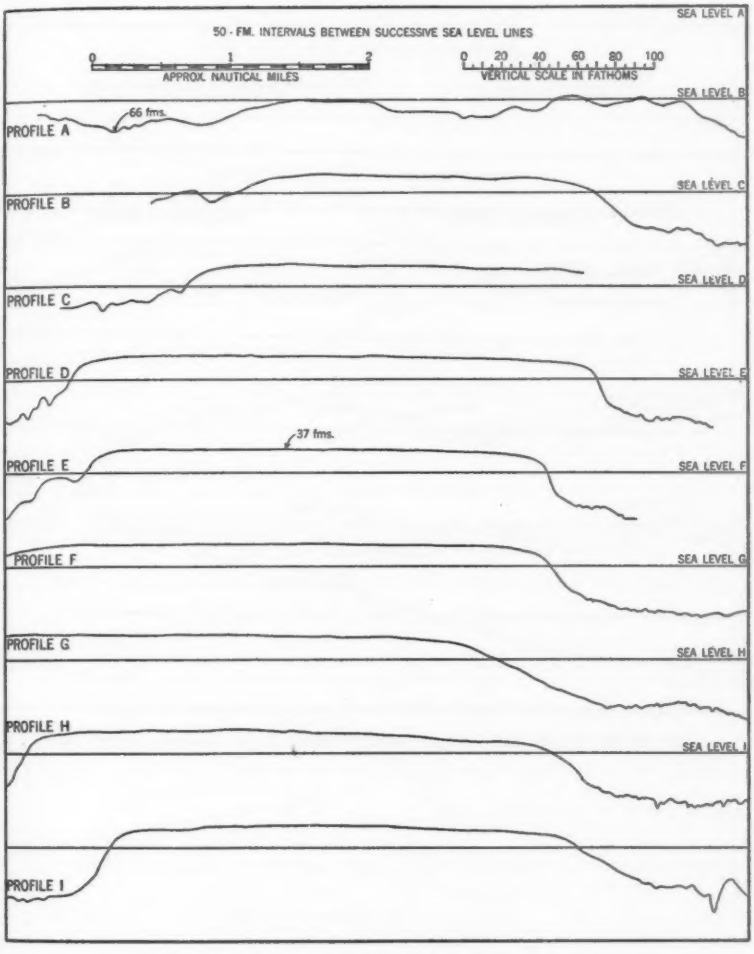


FIGURE 12.—*Fathogram profiles of Fippennies Ledge*

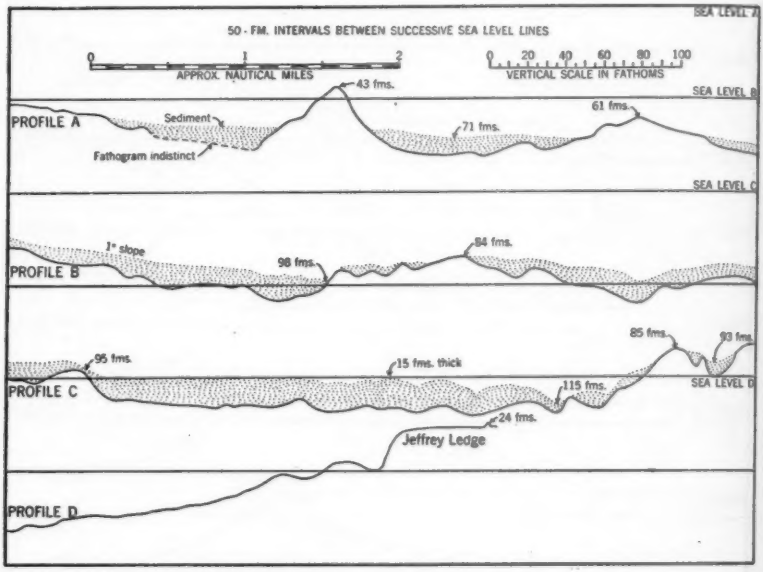


FIGURE 13.—*Continuous fathogram profile trending N. 75° E. across Jeffrey Basin*

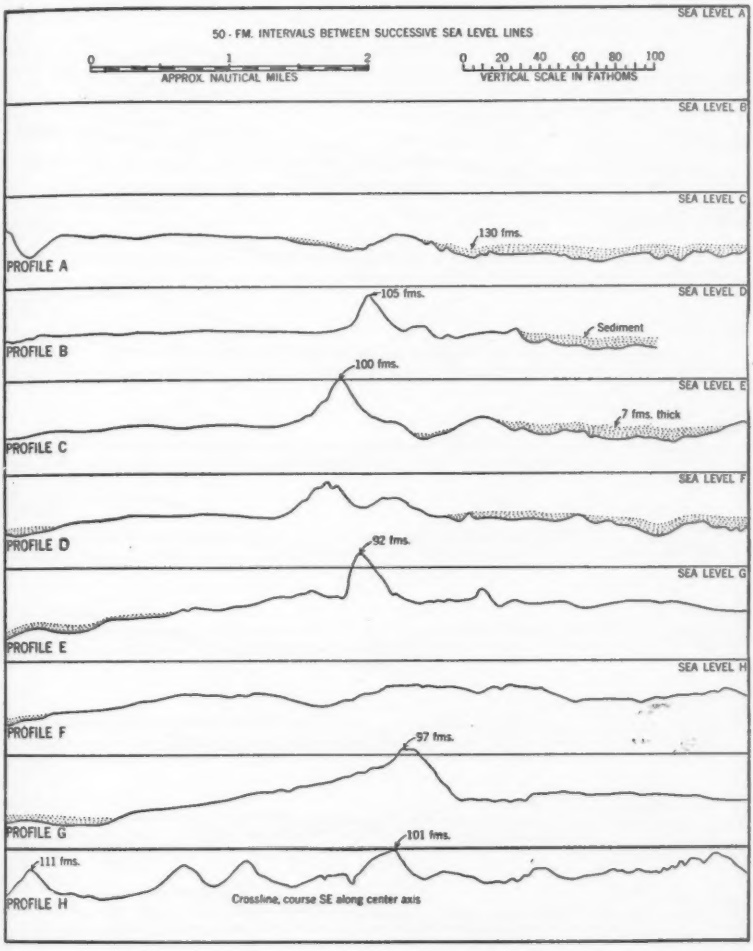


FIGURE 14.—*Fathogram profiles of south part of Mayo Swell*

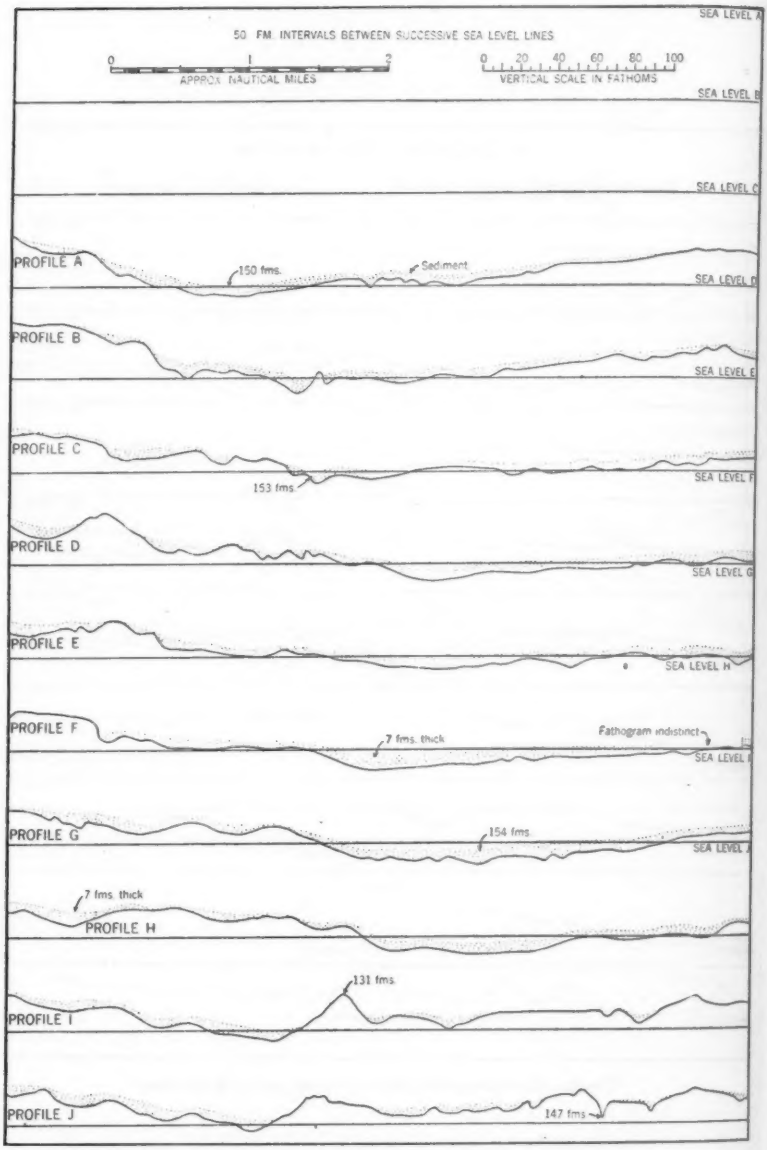


FIGURE 15.—*Fathogram profiles of south part of Murray Basin*

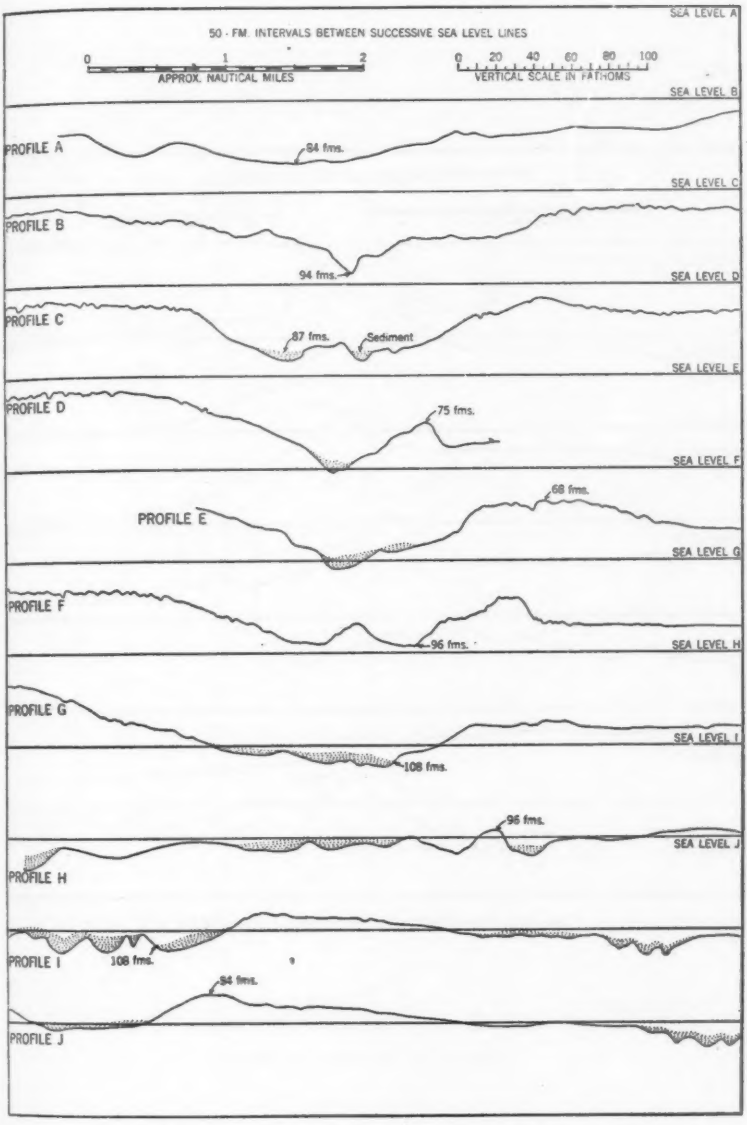


FIGURE 16.—*Fathogram profiles of depression west of Murray Basin*

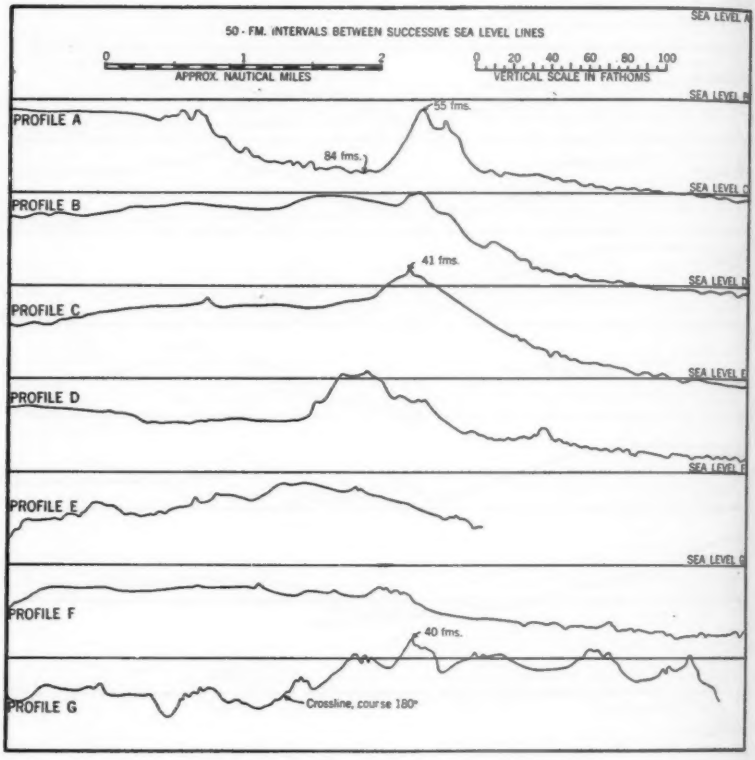


FIGURE 17.—*Fathogram profiles of Parker Ridge*

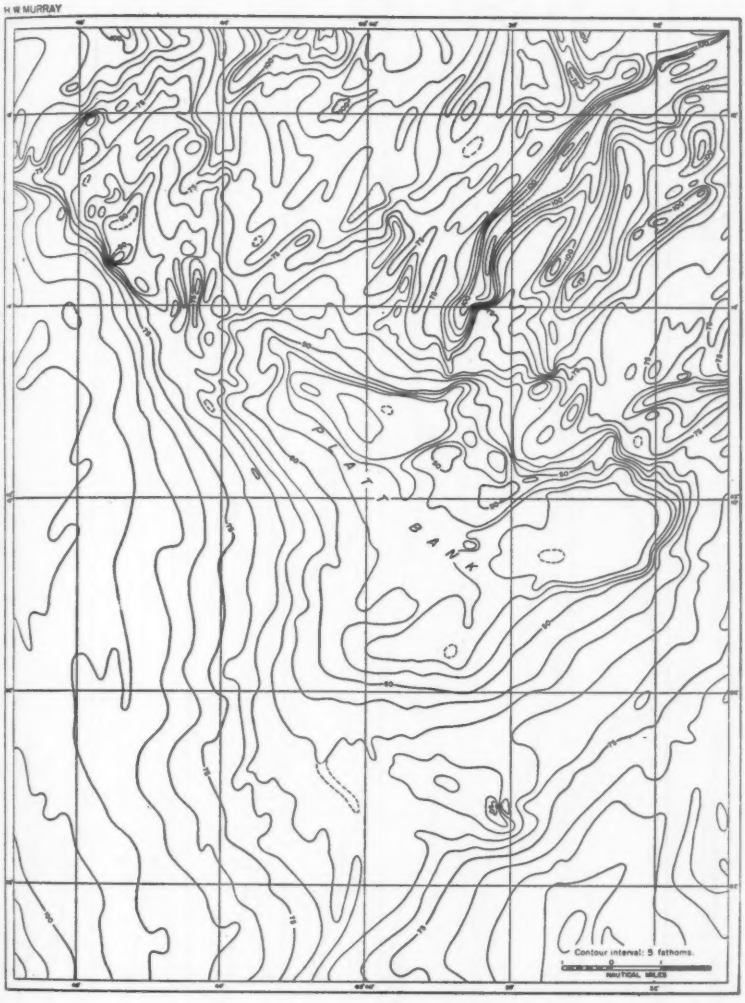


FIGURE 18.—*Contours of Platt Bank*

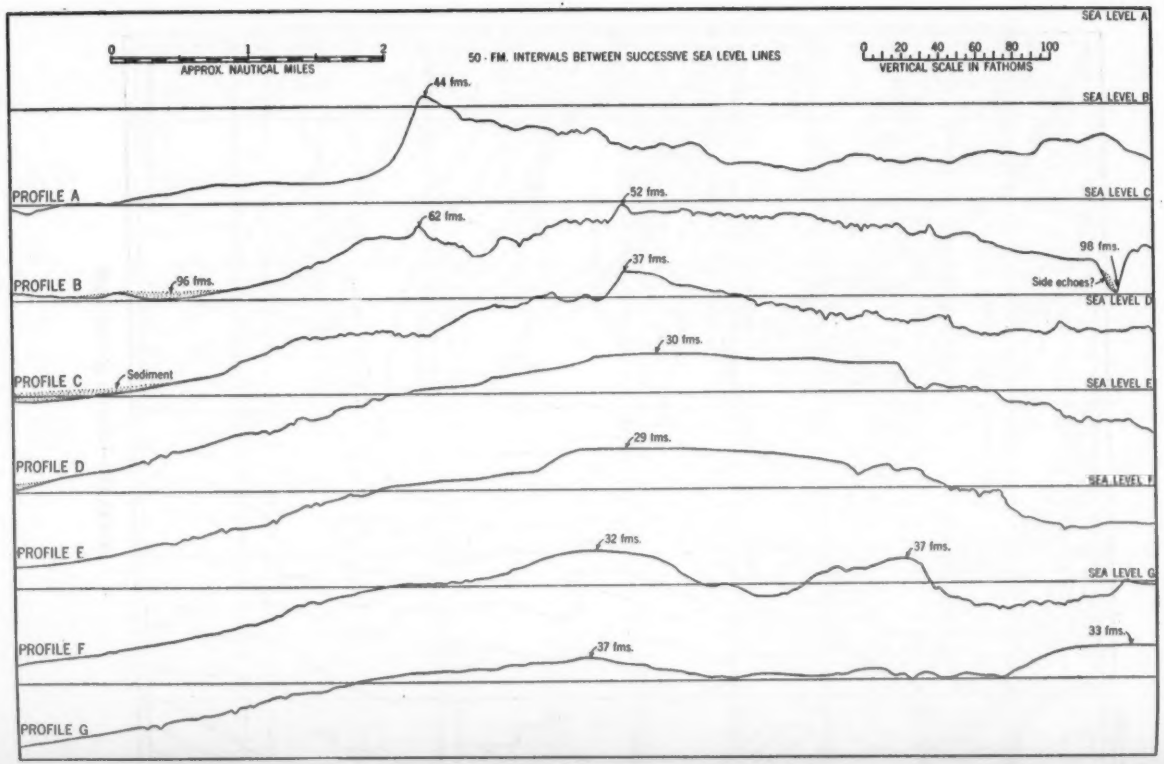


FIGURE 19.—*Fathogram profiles of north part of Platt Bank*

FIGURE 19.—*Fathogram profiles of north part of Platt Bank*

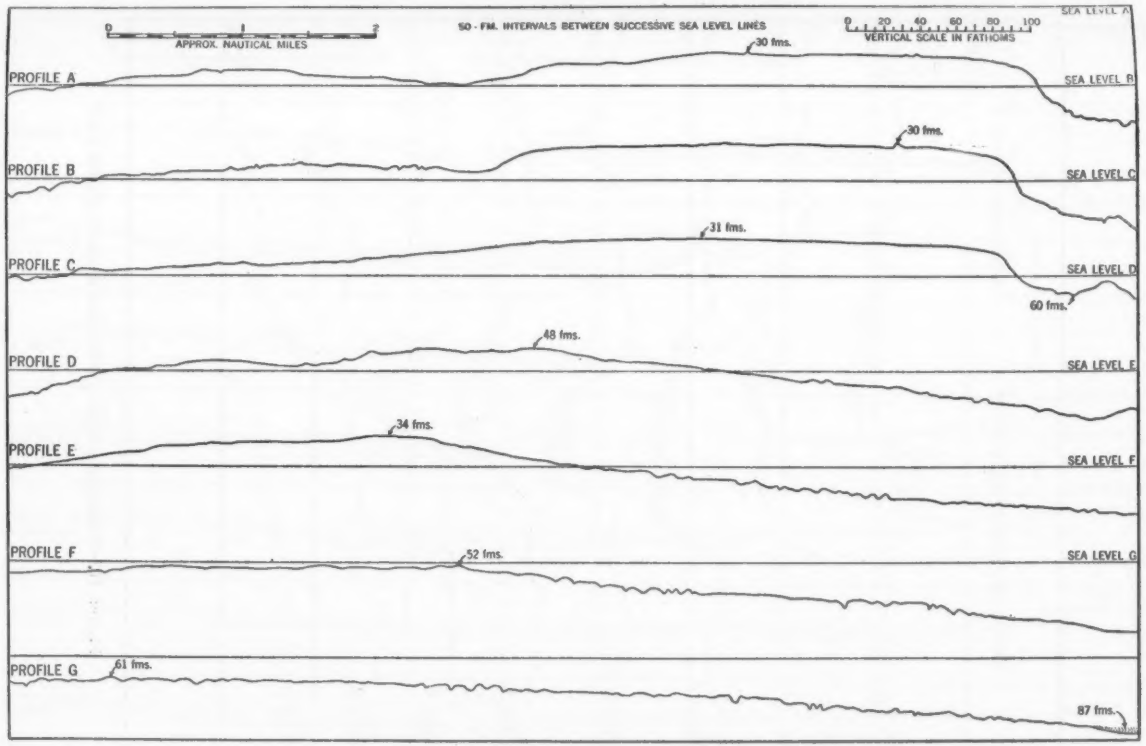


FIGURE 20.—*Fathogram profiles of south part of Platt Bank*

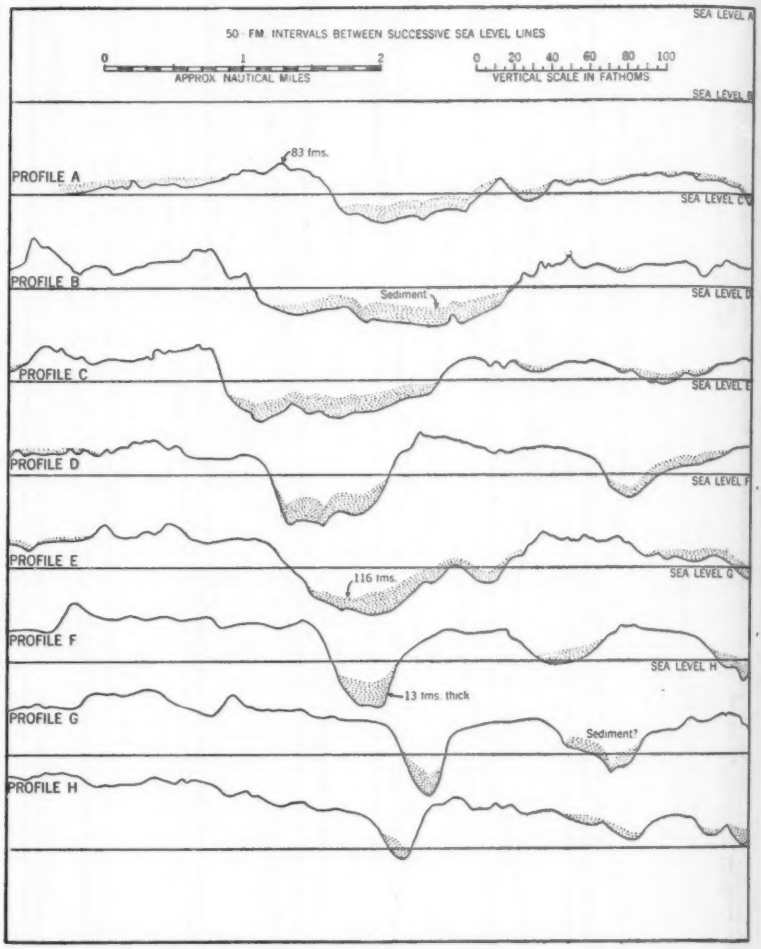


FIGURE 21.—*Fathogram profiles of depression northeast of Platt Bank*

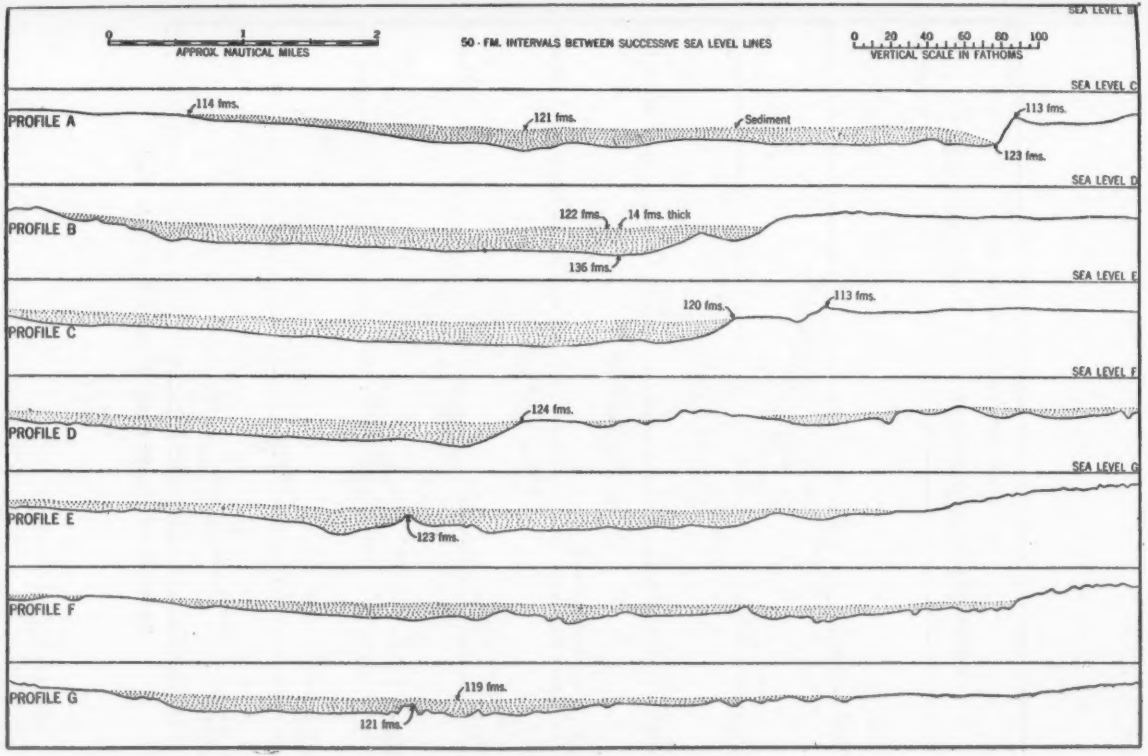


FIGURE 22.—*Fathogram profiles of Rodgers Basin*

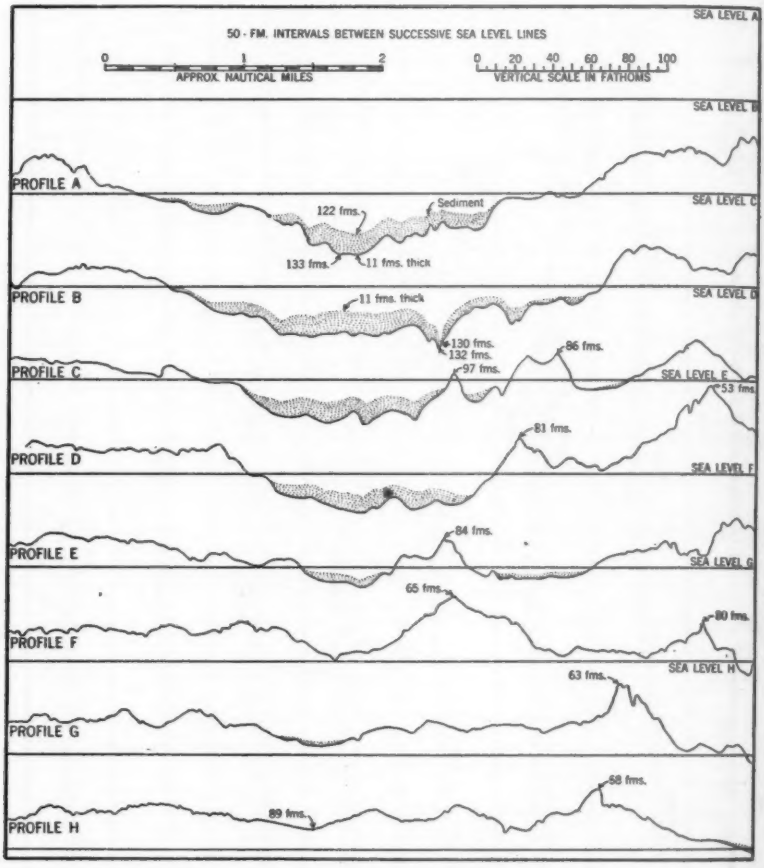


FIGURE 23.—*Fathogram profiles of south part of Sigsbee Basin*

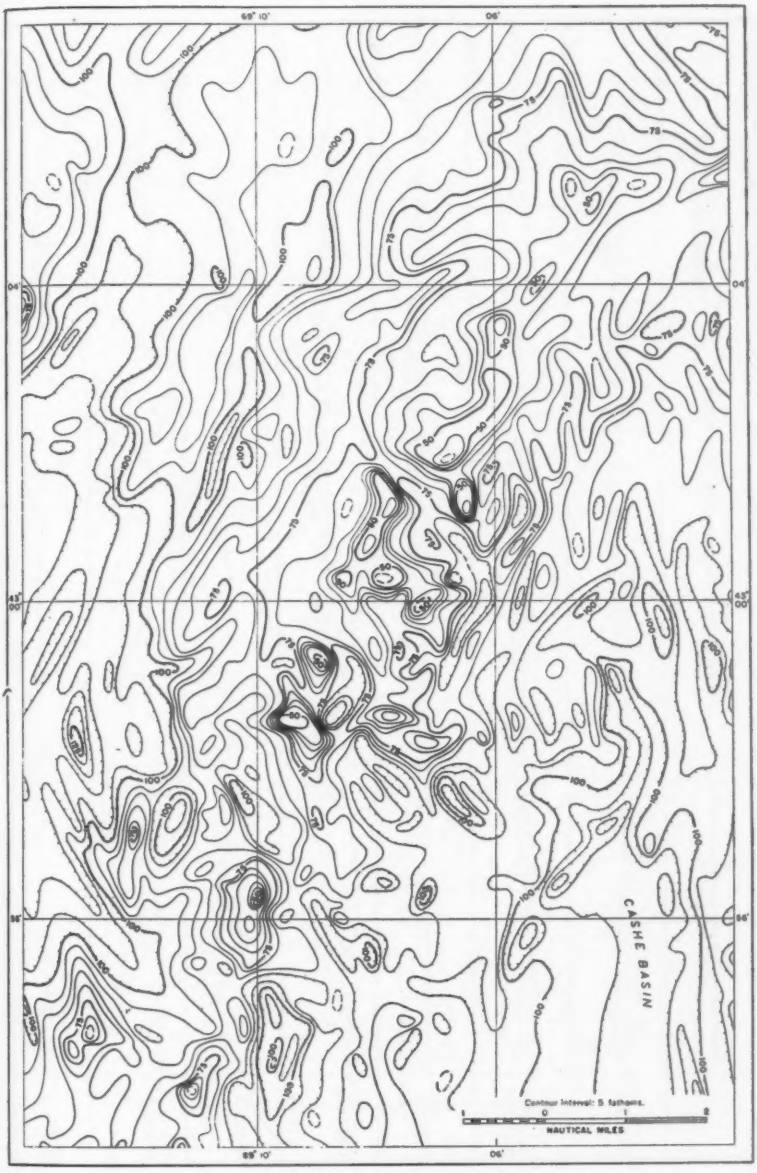


FIGURE 24.—*Contours of Sigsbee Knoll and Cashe Basin*

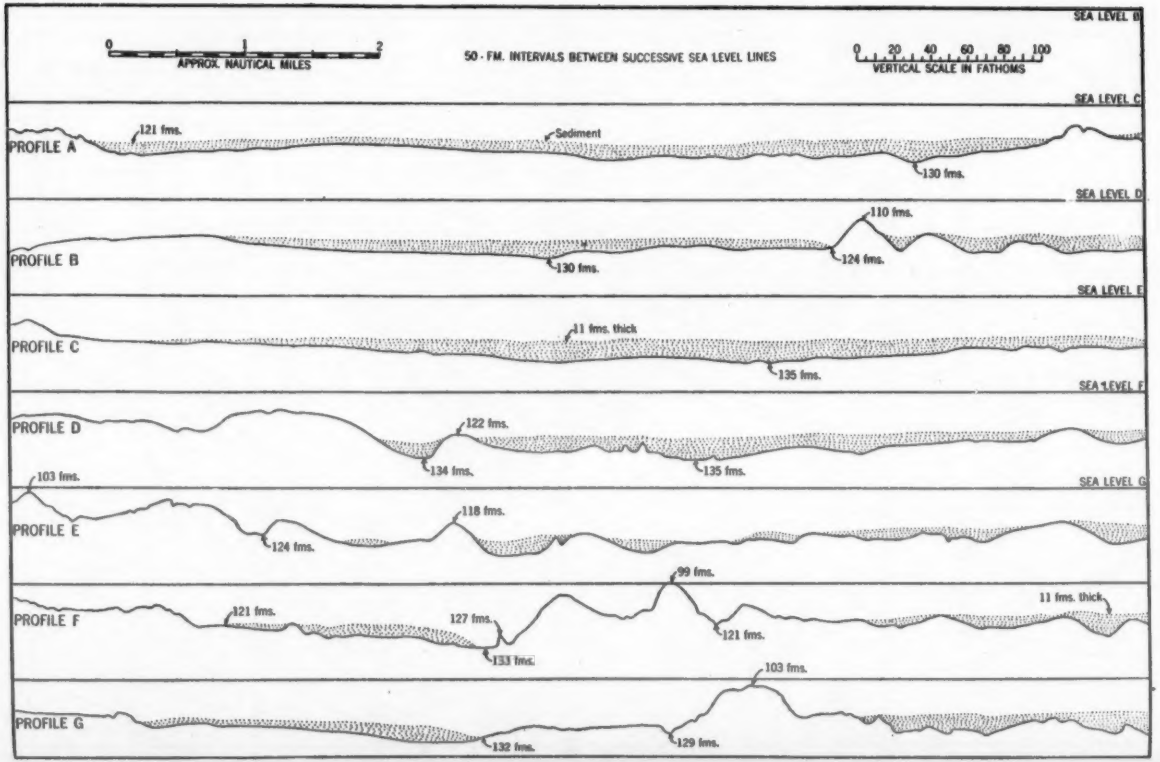


FIGURE 25.—*Fathogram profiles of Sharrer Basin*

FIGURE 25.—*Fathogram profiles of Sharrer Basin*

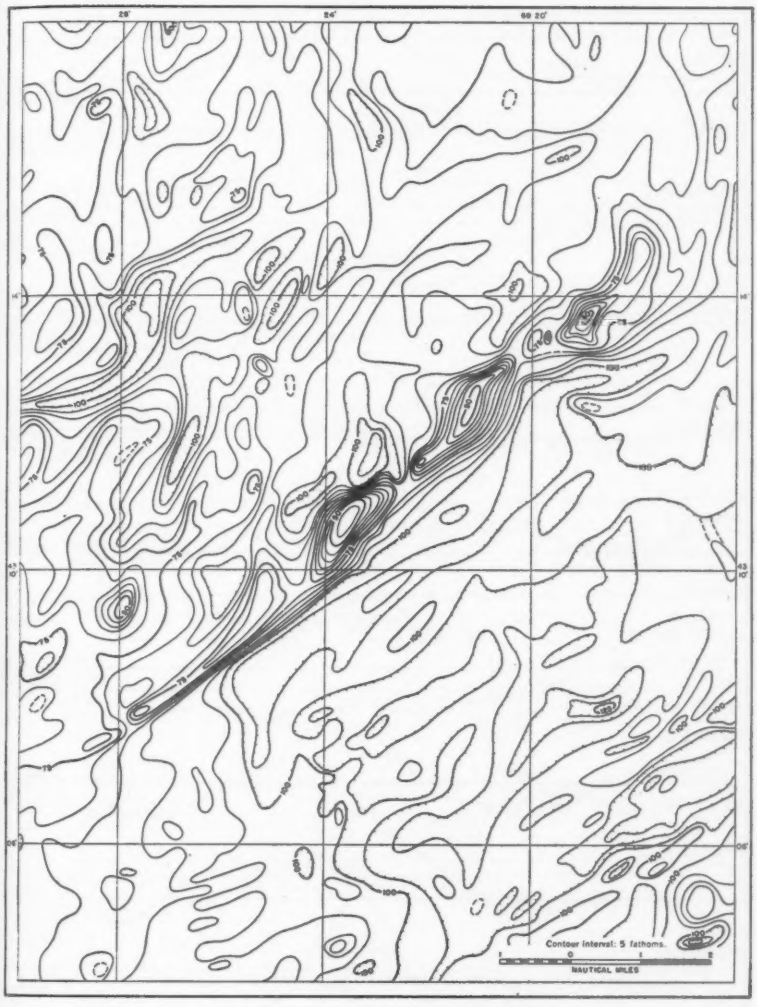


FIGURE 26.—*Contours of Three Dory Ridge*

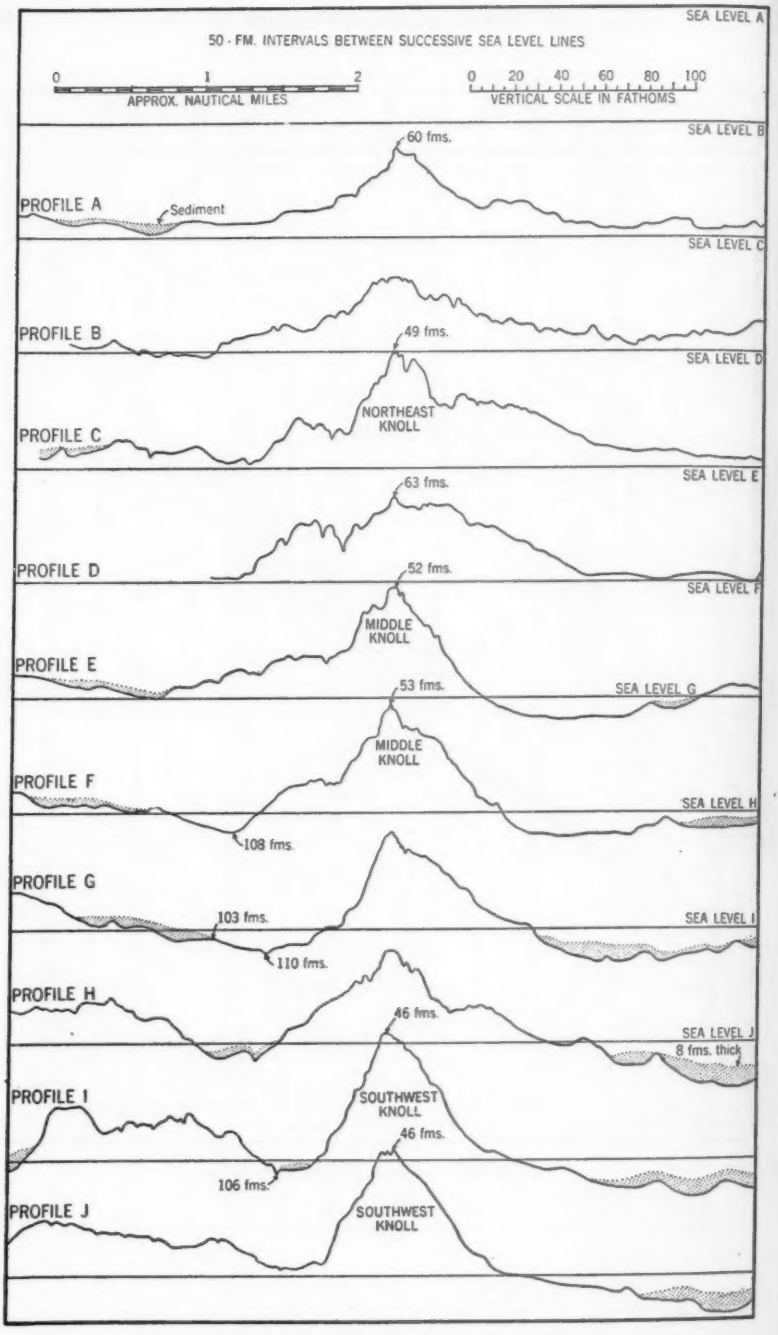


FIGURE 27.—*Fathogram profiles of Three Dory Ridge*

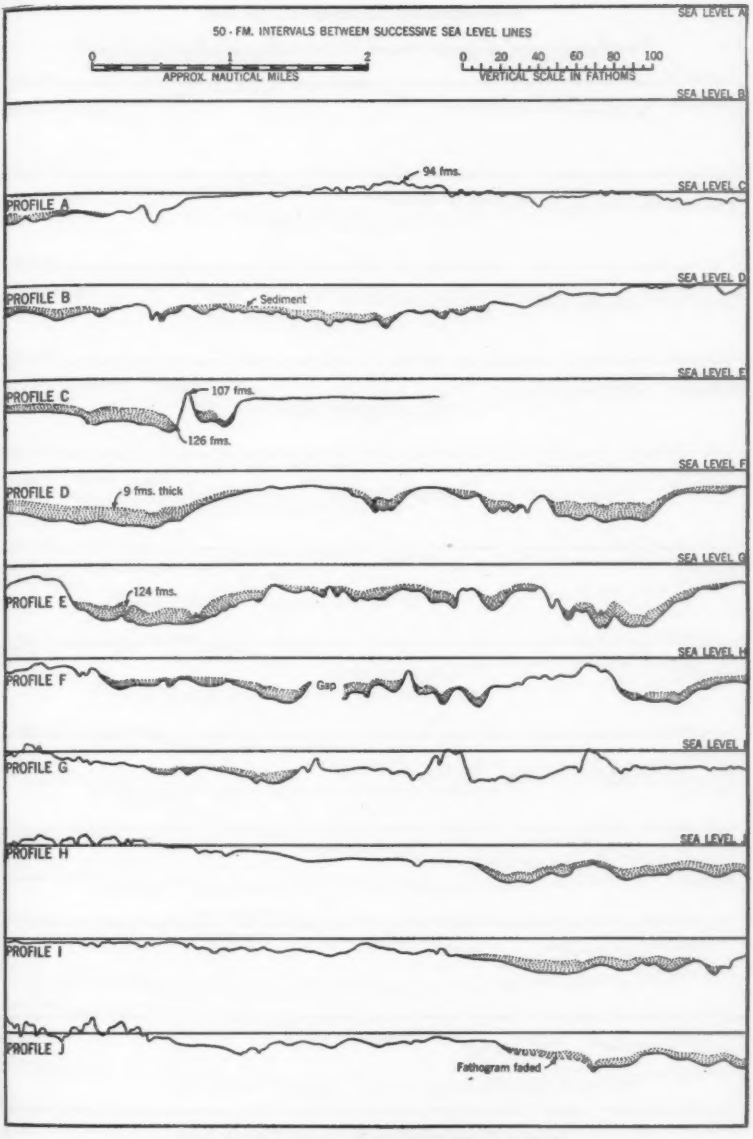


FIGURE 28.—*Fathogram profiles of Truxton Basin*

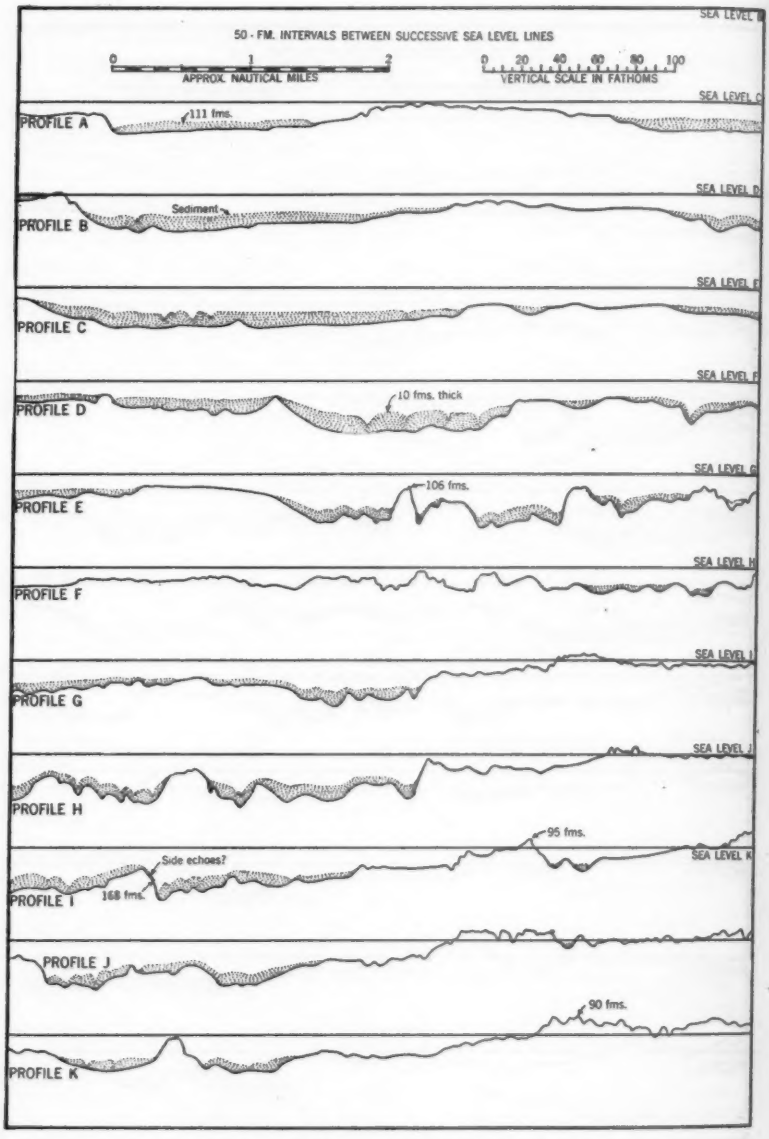


FIGURE 29.—*Fathogram profiles of Truxton Swell*

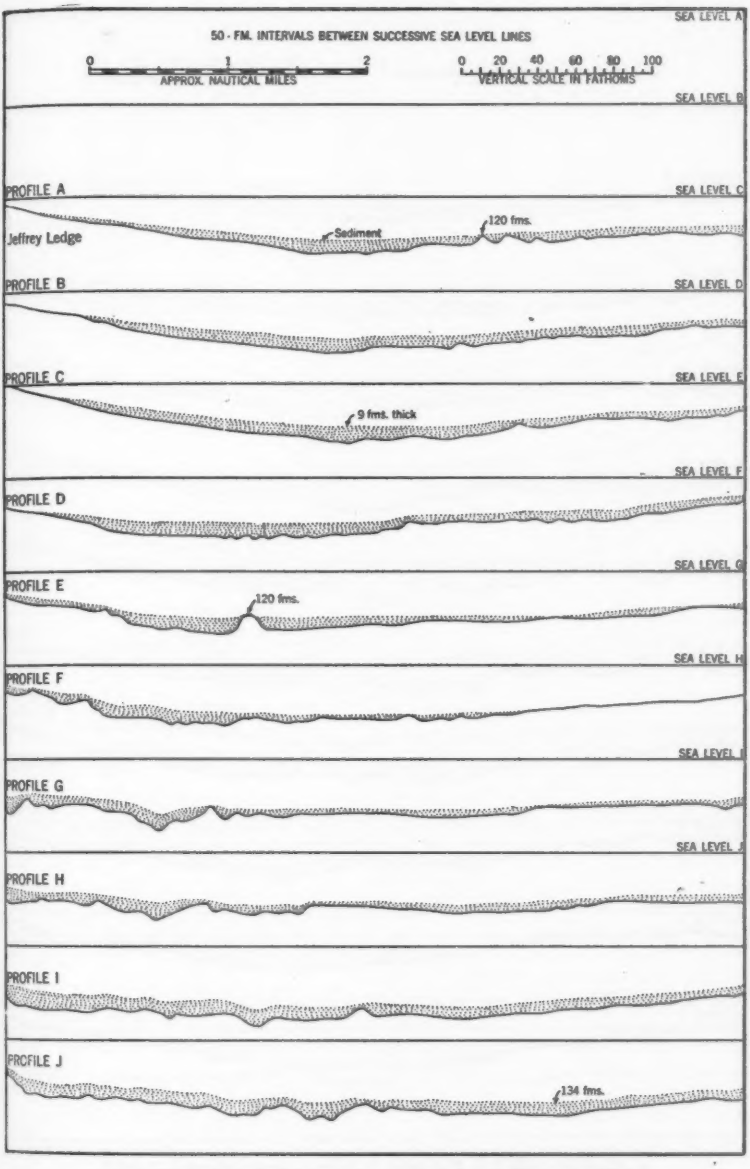


FIGURE 30.—*Fathogram profiles of north part of Wilkinson Basin*

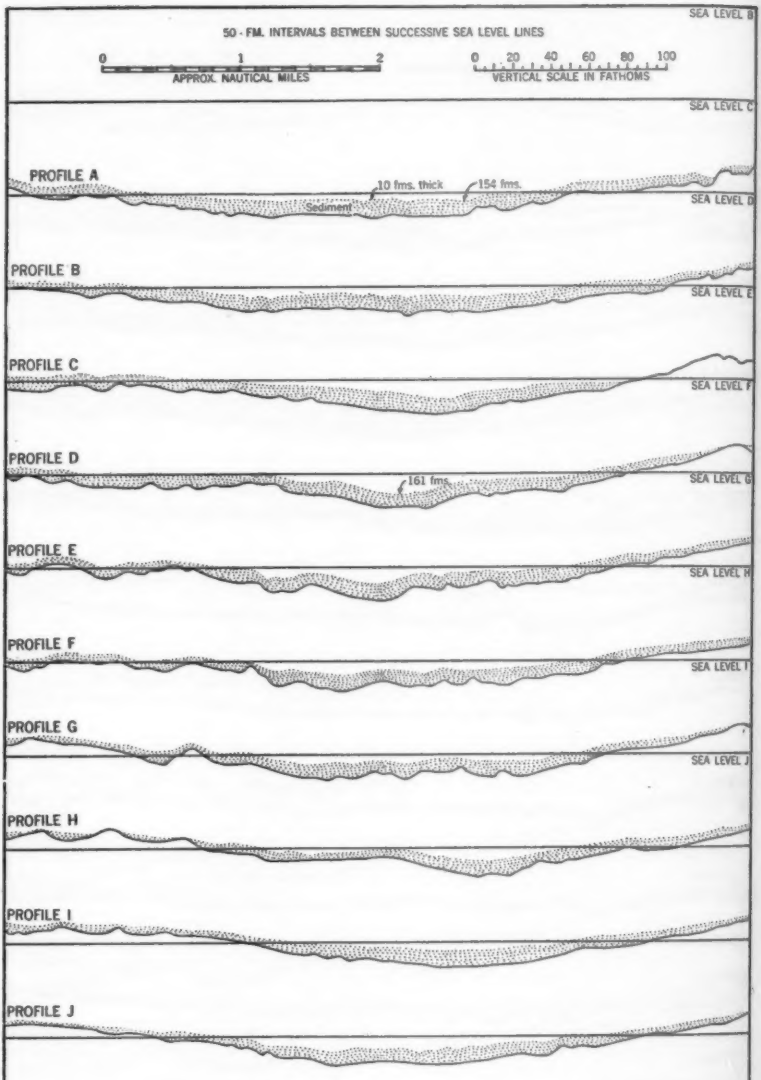


FIGURE 31.—*Fathogram profiles of middle portion of Wilkinson Basin*

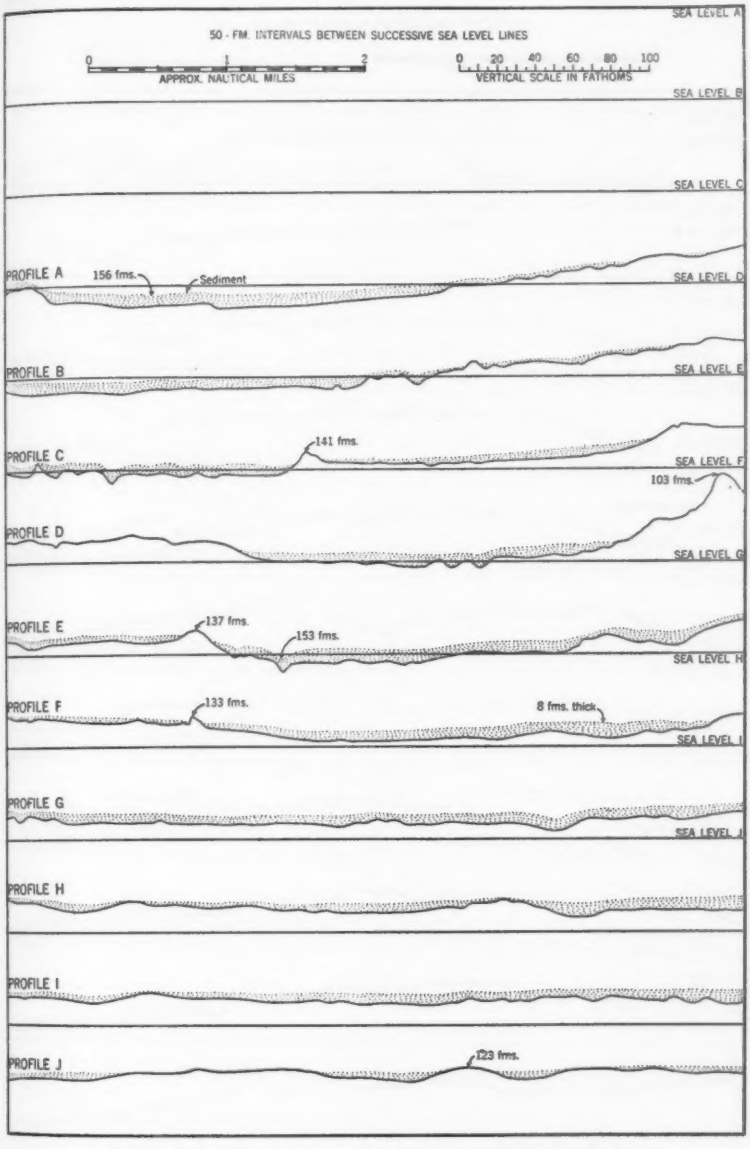


FIGURE 32.—*Fathogram profiles of south part of Wilkinson Basin*

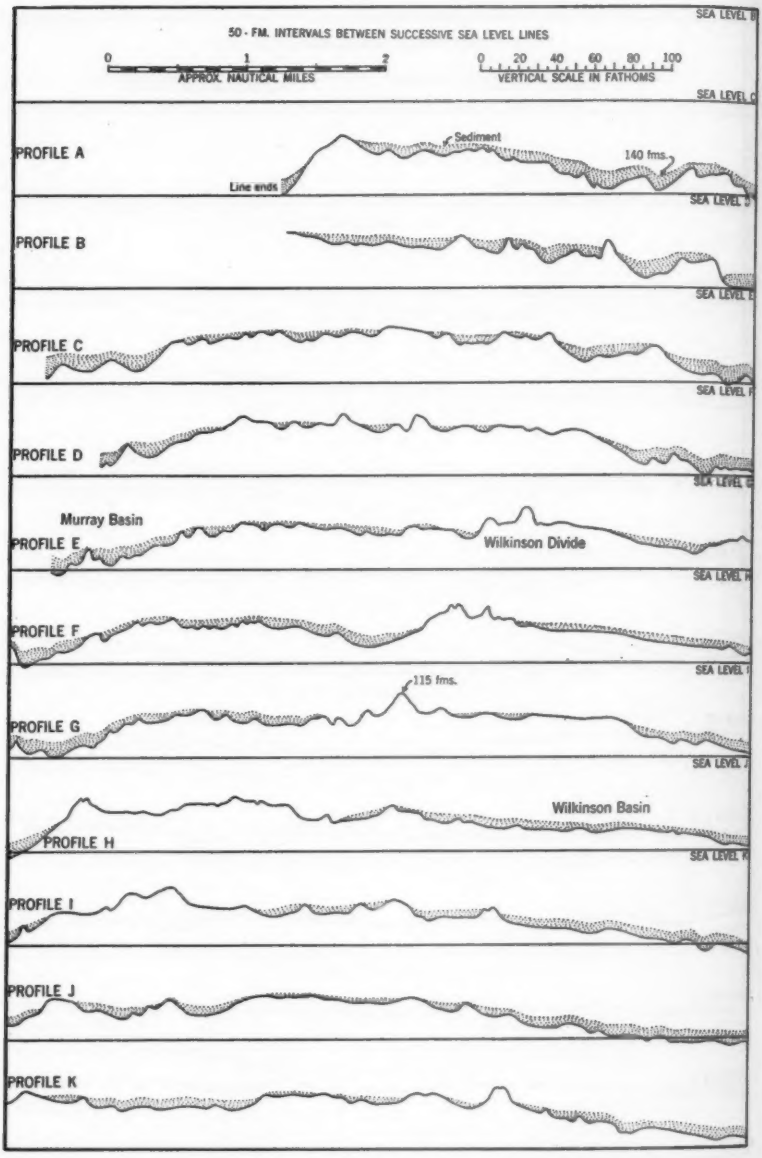


FIGURE 33.—*Fathogram profiles of north part of Wilkinson Divide*

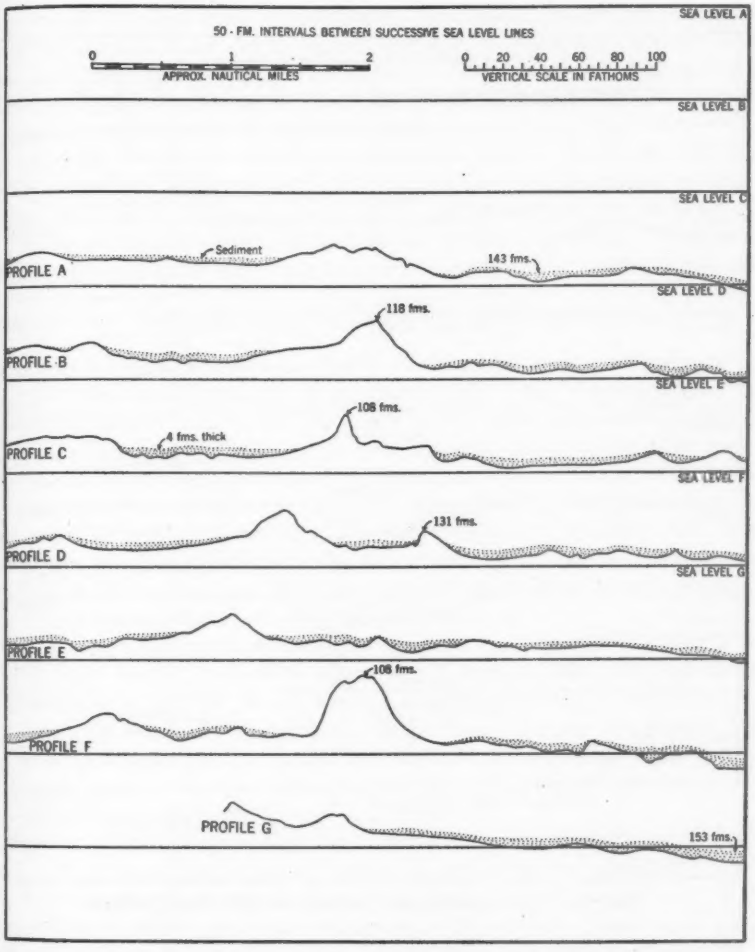


FIGURE 34.—*Fathogram profiles of south part of Wilkinson Divide*

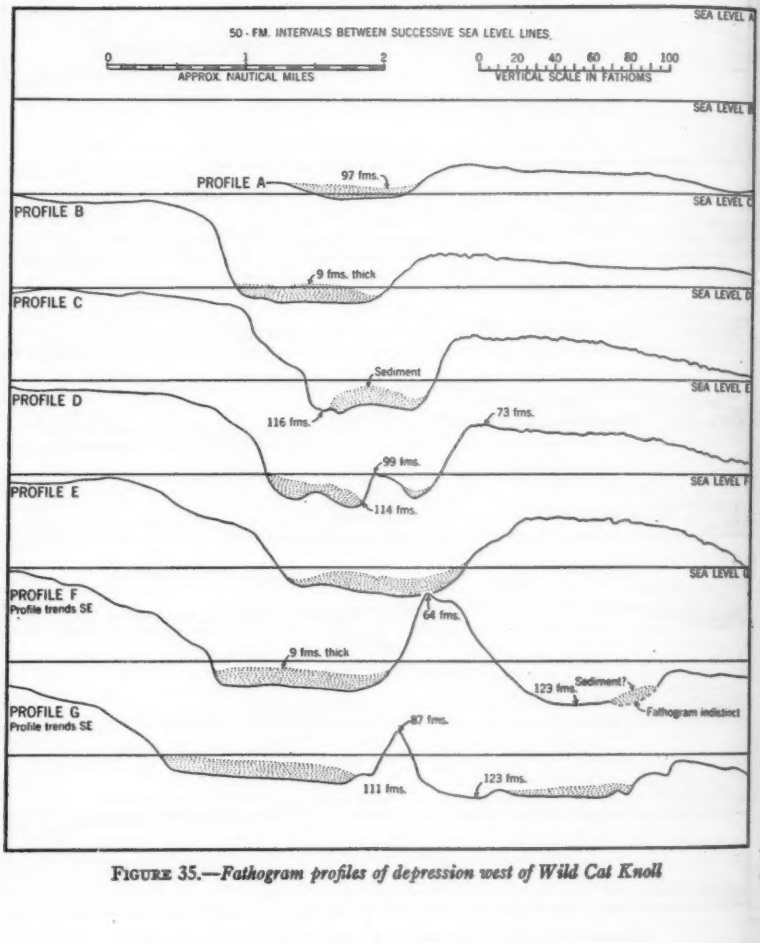


FIGURE 35.—*Fathogram profiles of depression west of Wild Cat Knoll*

Southeast of Cashe Ledge, Rodgers Basin (Pl. 4), trending south-southeast, is a dominant depression. It has a relatively smooth bottom and a maximum sedimentation of about 84 feet.

The features on Plate 5, the southeast portion of the present project, are characterized by milder relief. Accordingly, no fathogram profiles have been prepared. Wright and Stout swells comprise one feature shaped like an arrow head. Sewell Swell, like Davis Swell, is unique in that it trends east-west. Fathograms of Georges Basin, fronting the north side of Geroges Bank, and Lindenkohl Basin reveals no soft mud bottoms of any consequence.

In analyzing the deepest soundings in the basins listed in Table 3 and omitting for this comparison Wilkinson and Murray basins, one finds an average maximum depth of 126 fathom. Since the maximum is 133 fathoms and the minimum 118 fathoms, the extreme variation from the mean is only about 8 fathoms. The average maximum depth of these basins may have some bearing on the history of this area.

SEDIMENTATION IN THE GULF OF MAINE

A persistent feature noted in the Hughes Veslekari fathograms of this region is the dual bottom recorded mainly in the depressions. This is deduced from the two distinct recorder traces noted in the soft bottom areas as in Plates 9 and 10. Such dual bottoms were likewise apparent on the visual Dorsey III Fathometer. Moreover, in the southern portions of Wilkinson and Murray basins, echo returns from the upper surface were too weak, and soundings were necessarily read from the lower reflecting medium (Peacock, 1940). Conversely, the Veslekari fathograms gave a weak, but clear, separation of the two reflecting surfaces. Since all recorded soundings on the hydrographic sheet refer to the upper surface, it was necessary to correct the latter soundings from the Veslekari fathograms.

The dual-bottom phenomenon may be evidence suggesting sedimentation on an older surface. Locally, as in the southern part of Ammen Basin, this phenomenon could definitely be ascribed to side echoes. In this connection, an analysis of side echoes will be presented by the writer at a later date. However, it is doubted that this latter explanation could be applied to Rodgers Basin or to considerable portions of the other basins. In some instances, the slope of the upper reflecting surface may range from 20 to 70 per cent.

The nature of the material comprising these areas of sedimentation is not definitely known. No core samples have been taken, *i.e.*, to the writer's knowledge (1946). Available bottom characteristics, although numbering several hundred, usually indicate the nature of the top surface such as clay, mud, or sand. However, it cannot be stated whether such samples are from the top of the layer, near the bottom layer, or somewhere in between because a sounding wire suspended at such depth is invariably slightly deeper than that of an accompanying fathometer reading.

These sedimentation areas are generally found in basins or depressions at depths greater than about 80 fathoms. The sediment ranges in thickness from a thin film to about 90 feet. In general, it tends to smooth out minor bottom irregularities. An excellent example is Rodgers Basin (about 41 miles long and 10 miles wide)

where the fathograms indicate a thin film at the periphery and maximum thickness of about 84 feet near the center of the basin. Here, the upper surface is practically parallel to sea level, whereas the subsurface is approximately concave, as in a saucer. Soft bottom in this region also conforms with the topography of the subsurface as in the case of Blacks and Sigsbee basins but is conspicuously absent at occasional lower depths as in Sigsbee Basin and in the depressions on the sides of Three Dory Ridge. Obviously, absorbing problems have been presented which merit further investigation.

CONCLUSIONS

The foregoing material portrays the latest results of the U. S. Coast and Geodetic Survey's offshore work in these waters. The problems revealed are manifold and must be solved mutually by geologists, oceanographers, and hydrographic engineers. Two-thirds of the Gulf of Maine remains to be surveyed. This will be accomplished as soon as conditions permit. New data will undoubtedly be revealed, including additional information on the Fundian fault problem. However, most of the data will be evidence similar to that already revealed in the present project.

REFERENCES CITED

Adams, K. T. (1942) *Hydrographic manual*, rev. ed., U. S. Coast Geod. Survey, Spec. Pub. no. 143, p. 437–554.

Johnson, D. W. (1925) *New England Acadian shoreline*, John Wiley and Sons, 603 pages.

Peacock, F. L. (1940) *Season's report*, U. S. Coast Geod. Survey Archives, Project No. 248. Gulf of Maine, 15 pages.

Rich, W. H. (1929) *Fishing grounds of the Gulf of Maine*, U. S. Dept. Comm., Rep. Commissioner of Fisheries, App. no. III, p. 51–117.

Rude, G. T. (1944) *Safeguarding life at sea*, The Military Eng., vol. 34, p. 224–227.

Smith, Paul A. (1941) *Lands beneath the sea*, Sci. Mo., vol. LIII, p. 393–409.

U. S. Coast and Geodetic Survey, Washington, D. C.

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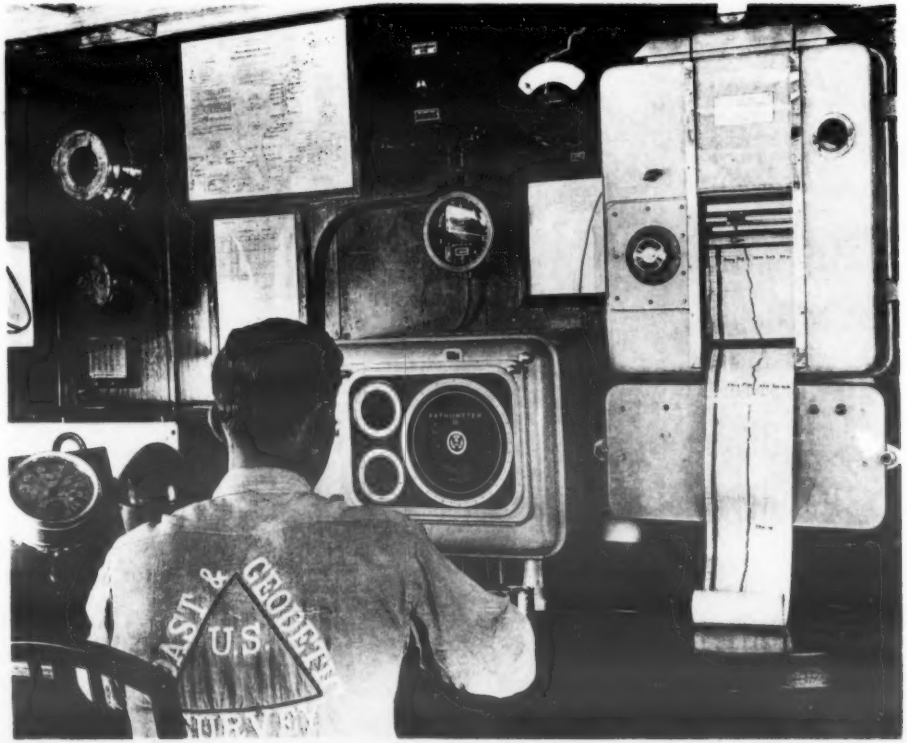
PLATES 6–12



FATHOMETER EQUIPMENT OF THE U. S. COAST AND GEODETIC SURVEY VESSEL OCEANOGRAPHER
(Courtesy of Life Magazine)

FATHOMETER EQUIPMENT OF THE U. S. COAST AND GEODETIC SURVEY VESSEL
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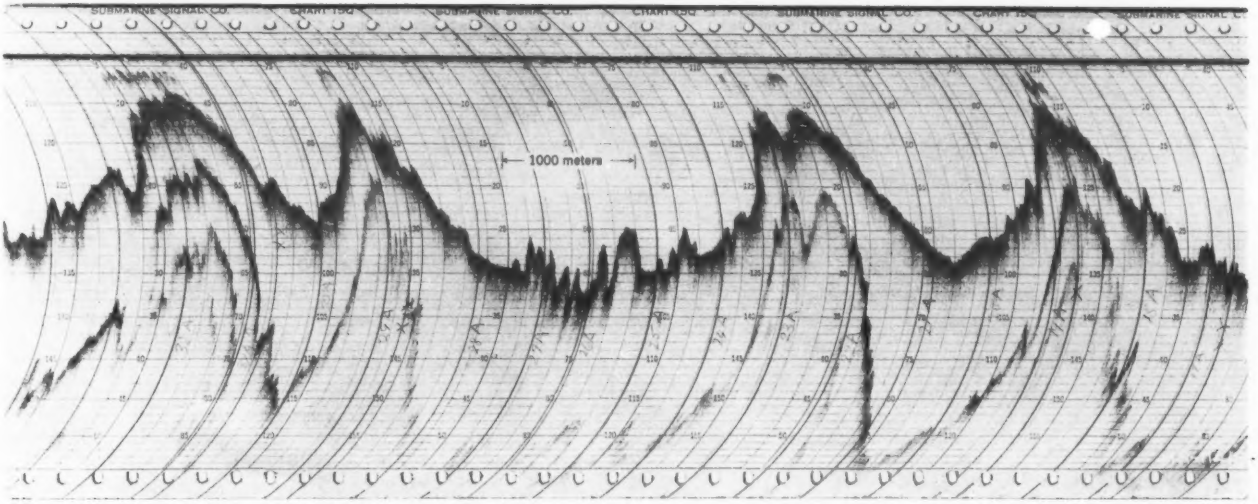
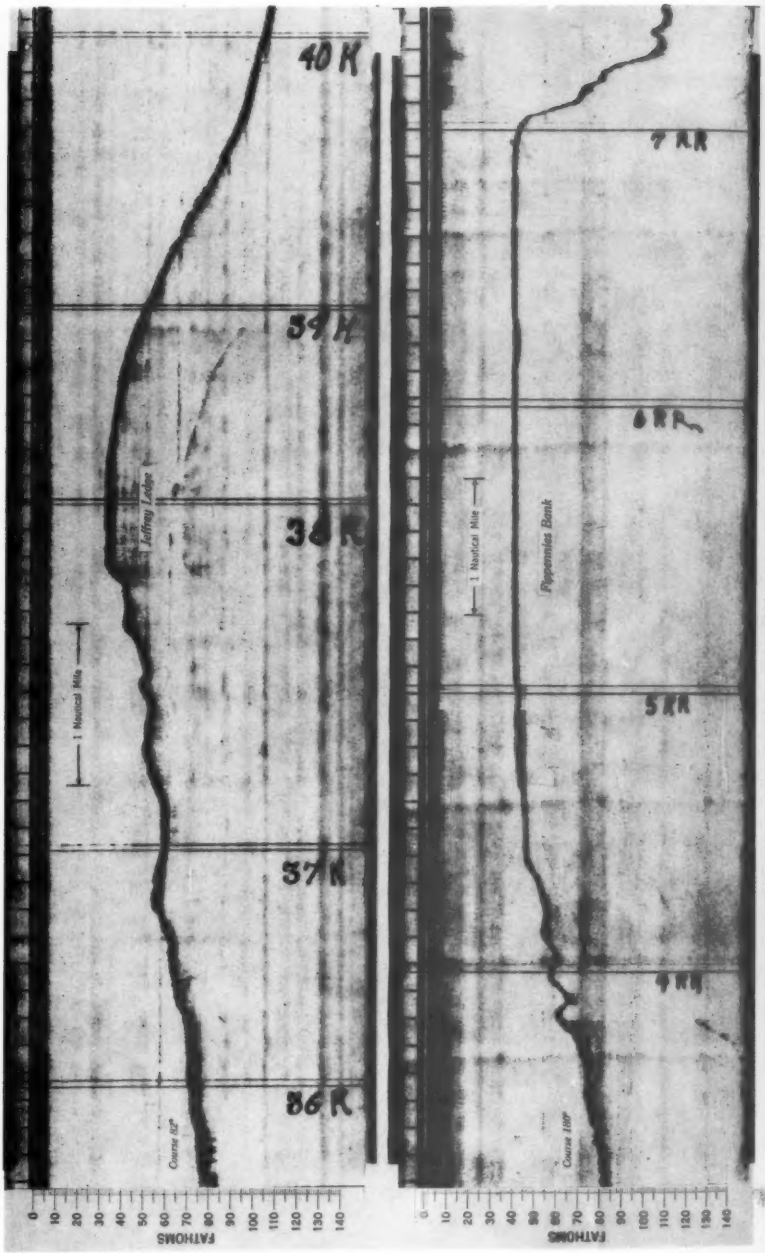
(Courtesy of Life Magazine)

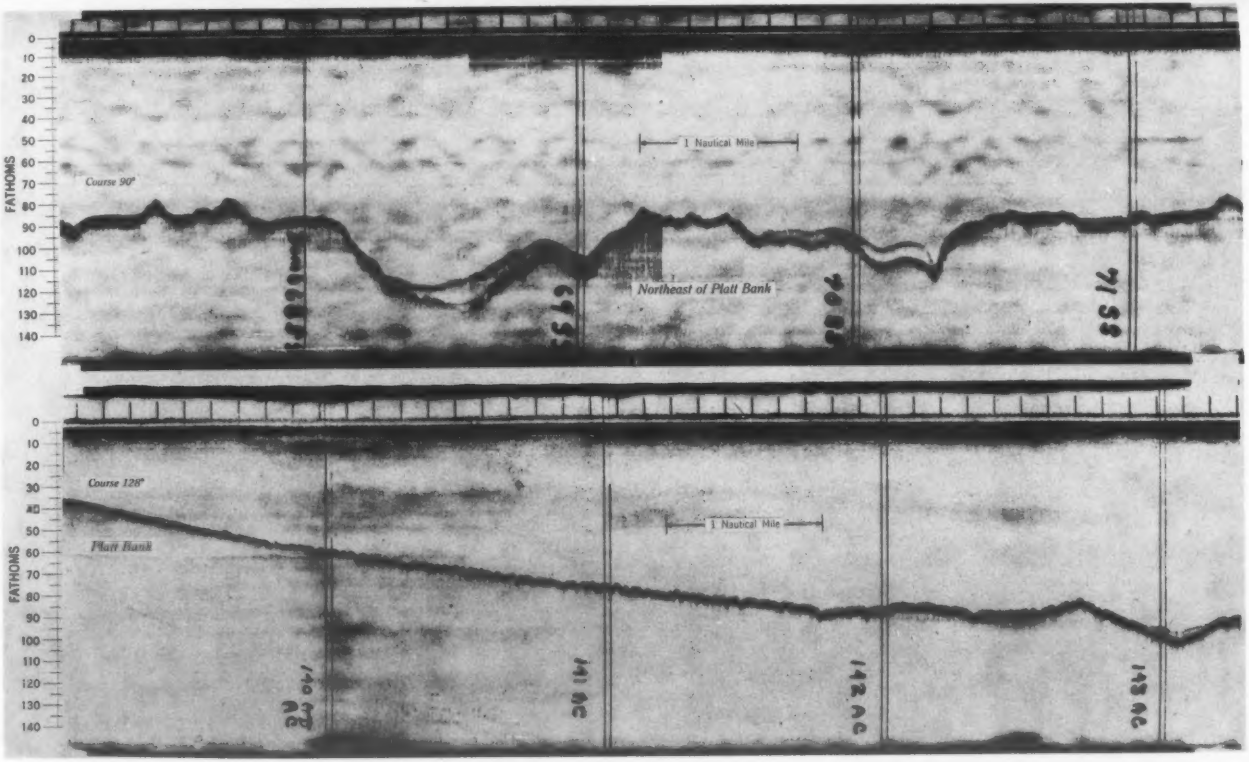


REDUCED PORTION OF TYPE 808 FATHOGRAM OF CASHE LEDGE
Soundings are read in feet along the arc of 0- to 55- foot scale.

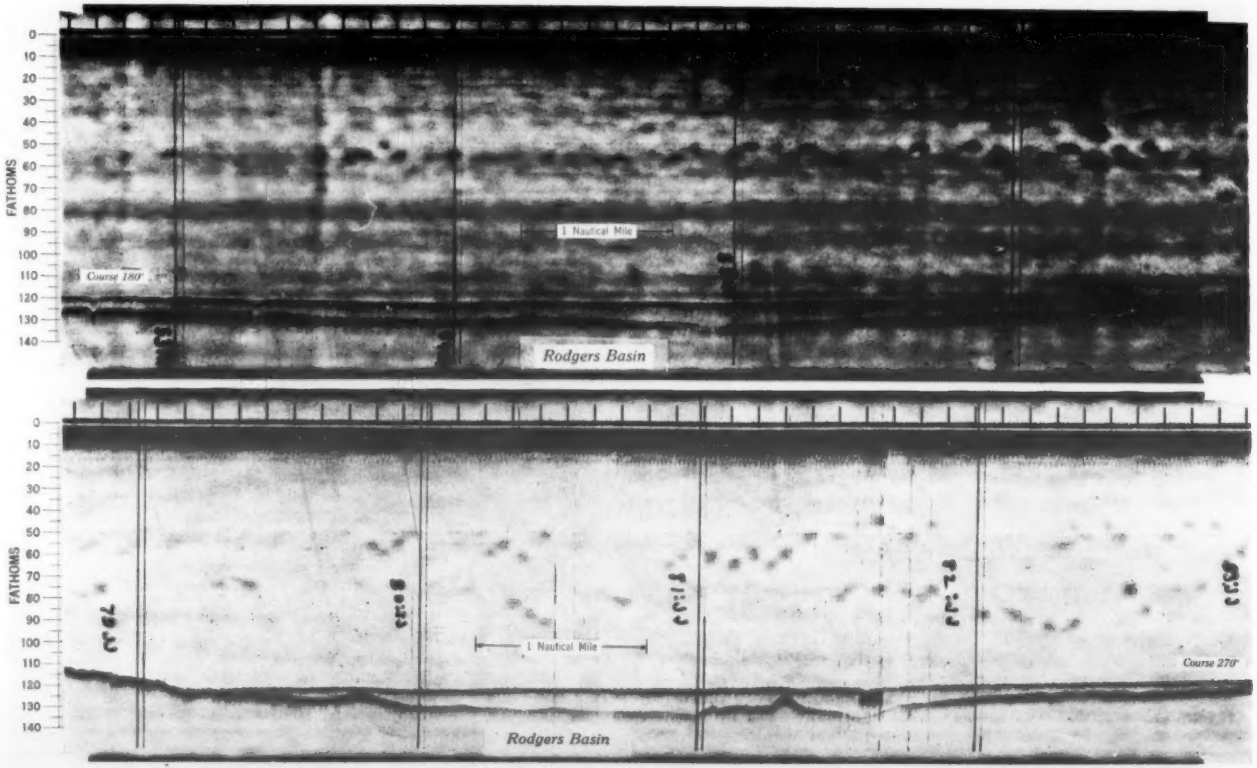


REDUCED PORTIONS OF VESLEKARI FATHOGRAMS OF JEFFREY LEDGE AND PIPPENNIES BANK

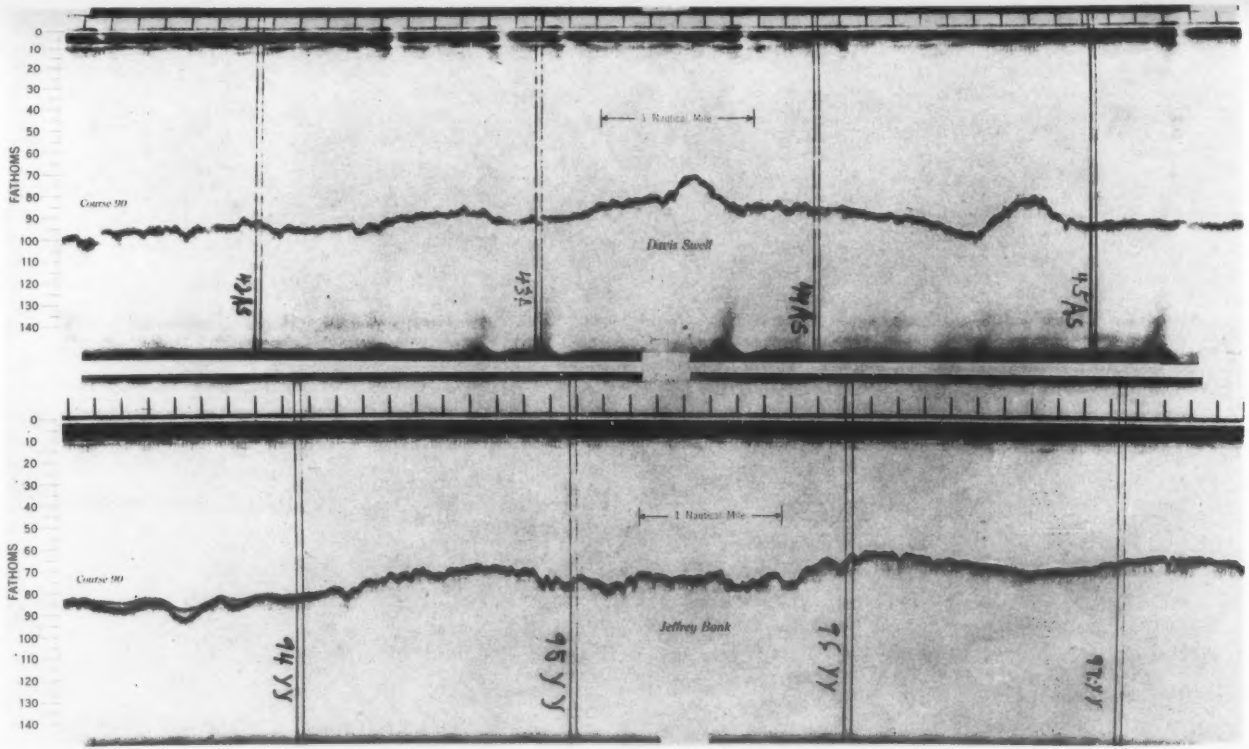
REDUCED PORTIONS OF VESLEKARI FATHOGRAMS OF JEFFREY LEDGE AND FIPPENNIES BANK



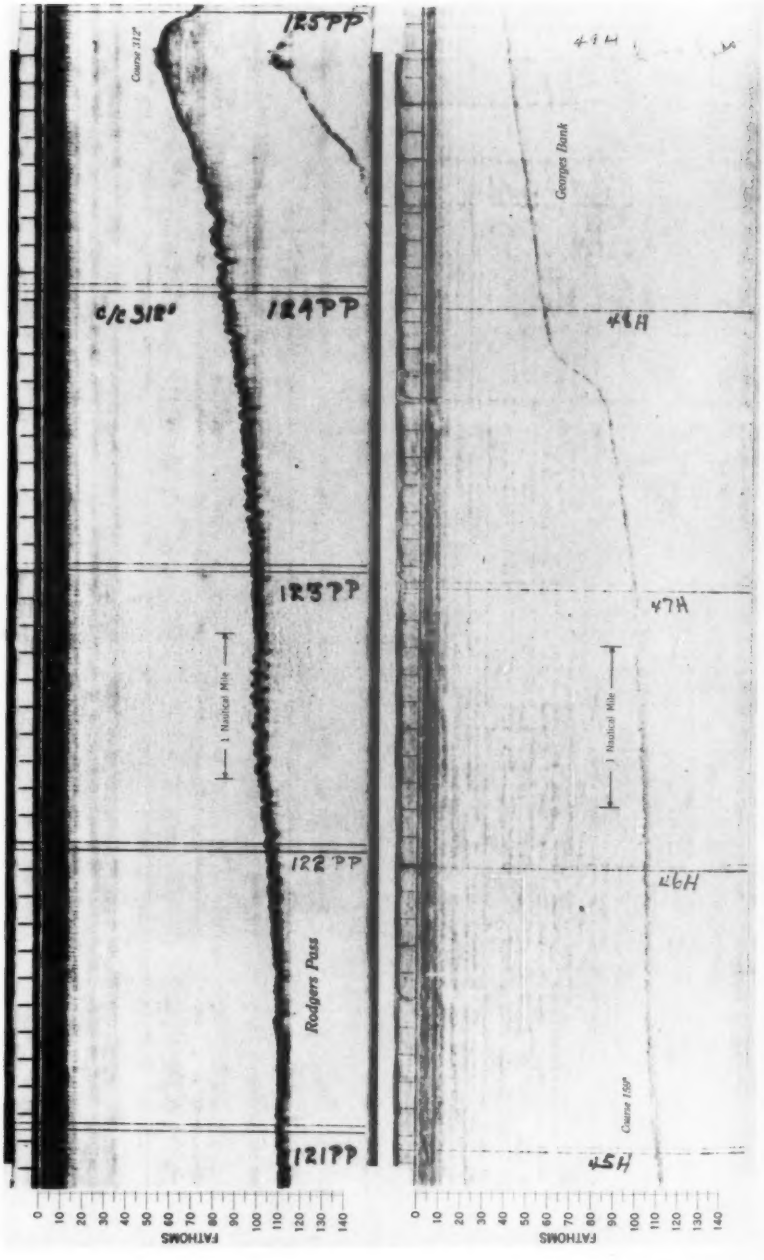
REDUCED PORTIONS OF VESLEKARI FATHOGRAMS IN THE VICINITY OF PLATT BANK



REDUCED PORTIONS OF VESLEKARI FATHOGRAMS CROSSING RODGERS BASIN AT RIGHT ANGLES



REDUCED PORTIONS OF VESLEKARI FATHOGRAMS OF DAVIS SWELL AND JEFFREY BANK



REDUCED PORTIONS OF VESLEKARI FATHOGRAMS OF RODGERS PASS AND GEORGES BANK

OFFICIAL CALENDAR

March 15	Final date for filing applications for grants to be considered at April Council Meeting
March 19–22	Meeting of Am. Inst. Min. Metall. Eng. and Soc. Econ. Geol., New York, N. Y.
March 24–27	Meeting of Am. Assoc. Petrol. Geol., Los Angeles, Calif.
April 5	Meeting of Committees on Publications and Projects, G. S. A. House, New York, N. Y.
April 11–12	Meeting of Cordilleran Section of G. S. A., Stanford University, California
April 26	Council meeting, G. S. A. House, New York, N. Y.
April 28–30	Meeting of Am. Geophys. Union, Washington, D. C.

REDUCED PORTIONS OF VESLEKARI 'FATHOGRAMS OF RODGERS PASS AND GEORGES BANK